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Some Aspects of the Glacial Deposits of Essex

by K. M. CLAYTON

Received 28 December 1955; Read 5 April 1957

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ABSTRACT: The geological mapping of the area around Chelmsford and the plotting and analysis of the borehole information from Harlow New Town, fill two important gaps in our knowledge of the Essex drifts. The establishment of a sequence for the glacial drifts makes it possible to compare the Essex drift country with the better known area west of the Lea. Both the Harlow and Chelmsford areas show three boulder clays deposited during two separate glaciations. The drifts belonging to each glaciation rest on surfaces eroded to two widely separated base-levels, and these levels are correlated with the known chronology of the Middle Thames to give an outline chronology for the River Thames in Essex.

Part 1. THE GLACIAL DRIFTS OF THE AREA AROUND CHELMSFORD

(a) **Introduction.** In the past, most interpretations of the drifts of Essex have rested on comparisons with Norfolk and North Suffolk where the glacial deposits are well exposed in the cliffs. Any complete account of the Essex drifts is hindered by the absence of large or continuous sections. The following description of the Essex drifts is based on the mapping of an area of about seventy square miles on a scale of six inches to the mile.[1] It is roughly triangular in shape and extends from Chelmsford, south to Billericay and east to Maldon (Fig. 1). Part of this area was mapped by Mr. Selwyn Turner in 1934 and he led members of the Association on the occasion of a field meeting at Great Baddow and Danbury in 1936 (Turner, 1937). The geological mapping was carried out with the help of a soil auger, and has been supplemented in several areas by borings put down by gravel companies. In addition, a number of auger holes have been made to determine the depth of leaching of the boulder clays found in the area.

The Old Series geological map (Sheet 1, NE.) shows the general pattern of the drifts quite satisfactorily, although inevitably it needs correction on matters of detail. The area can be divided into three regions on the basis of the published geological map. To the north-west, an extensive sheet of boulder clay occupies the interfluves, while an underlying sheet of glacial gravel outcrops on the sides of the larger valleys. These two deposits slope gently towards the south-south-east, and reach the line of the lower Chelmer and Blackwater. Beyond the River Chelmer the ground rises and the high ground is occupied by patches of boulder clay but glacial gravels are absent except on Danbury Hill. The southern limit of glaciation is reached along the north side of the Crouch Valley, and the ground to the south is free of glacial drifts.

It will be shown that these three divisions are of considerable significance. The area has been glaciated on two separate occasions and the differences noted on the geological map are the result of differences in the ages of the glacial deposits. The more recent of these two glaciations deposited the boulder clays and gravel north-west of the Chelmer–Blackwater, and extended only a little way beyond that line up the valleys of the Wid and Sandon Brook. The dissected sheet of boulder clay, occupying the more southerly area and largely unassociated with gravel, is of far greater age and is the ground moraine of the first glaciation of this part of Essex. It is the greater extension of this earlier ice-sheet that has resulted in the preservation of the deposits over such a wide area. Both these glaciations belong to the Older drift, and deposits of Newer drift age are confined to river terraces and valley brickearths.

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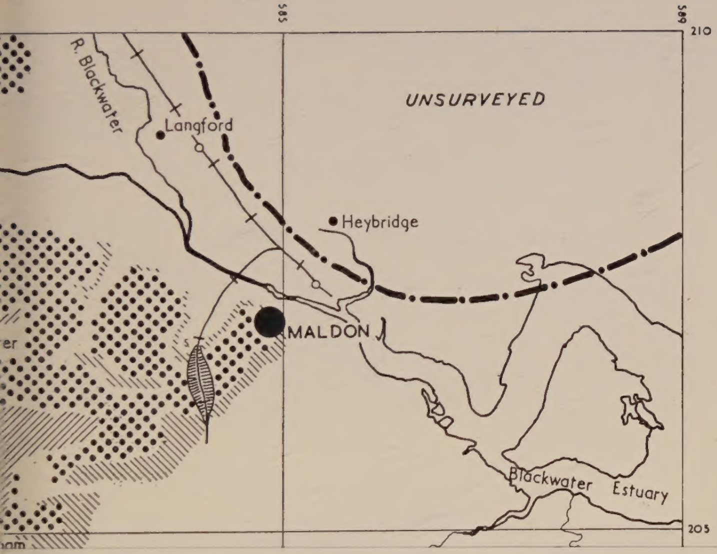
[1] Editor's Note. All National Grid References lie within the 100 Km. square 52/......


585
589
210
205
UNSURVEYED
R. Blackwater
Langford
Heybridge
MALDON
er
S
Blackwater Estuary
am

(b) **Springfield Till.** The younger glacial deposits north of Chelmsford are in the form of a 'sandwich', consisting of two boulder clays separated by glacial gravels. The upper member of the sequence is a chalky boulder clay, a characteristic blue-grey chalky clay with frequent fragments of angular flint, rounded flint pebbles from Eocene or later deposits, rounded pebbles of Bunter quartzite, fragments of chalk and occasional erratics derived from igneous and sedimentary rocks lying north and north-west of the area. The matrix is weathered to an orange-brown colour towards the surface, while the actual surface layers are leached free of chalk, the base of the leached zone forming quite a distinct line. This boulder clay reaches a maximum thickness of 30–40 ft. near Chelmsford, but further north it becomes very thick on the interfluves, as is shown by many wells which pass through more than 100 ft. of the deposit before entering the glacial gravels. In the present area it covers most of the parish of Springfield and will be called the 'Springfield Till'. This chalky boulder clay was described by Harmer as the principal boulder clay of much of East Anglia (i.e. the so-called 'Great Chalky Boulder Clay') and he named the ice-sheet which deposited it, the Great Eastern glacier (Harmer, 1904, 1909).

(c) **Chelmsford Gravels.** The glacial gravels that underlie the Springfield Till were described by S. V. Wood (Jnr.) (1865) as the 'Mid-glacial gravels', for in the cliff section at Corton, glacial gravels lie between two boulder clays. He identifies nearly all the glacial gravels of East Anglia with his Mid-glacial deposits but a more restricted local term is desirable and 'Chelmsford Gravels' will be used here in this connection. Normally the gravels are some 30 ft. thick and consist of bedded deposits ranging from pure sand to coarse boulder beds. In the Chelmsford area several beds resembling boulder clay appear towards the top of the deposit and appear to mark stages when the ice-edge oscillated slightly and the outwash material was less thoroughly sorted. Occasionally thick silty bands are seen as, for example, at the Boreham pit (756117). The gravels contain much the same suite of erratics as the boulder clays and many of the angular flints are very little rolled. On the other hand, chalk is normally absent in this area.

(d) **Maldon Till.** The Chelmsford gravels overlie a discontinuous boulder clay here called the 'Maldon Till'. This deposit has a curious history. Earlier workers in East Anglia are divided into those who readily recognised a lower boulder clay beneath the glacial gravels and those who could find no evidence for such a deposit. As the deposit is rarely seen in section, a summary of the evidence for this lower boulder clay is clearly desirable. Difficulties seem to have arisen because any such lower boulder clay was held to be contemporary with the North Sea drift of the Norfolk coast. The few instances that S. V. Wood and Harmer described were poorly substantiated, if not entirely unfounded, and after examining these,

P. G. H. Boswell concluded that no such boulder clay was to be found south of the northern part of Suffolk (Boswell, 1914). Yet *The Geology of London*, vol. 1, includes an excellent description by W. Whitaker of the boulder clay exposed in the Maldon railway cutting (842065), outcropping *below* the glacial gravels (Whitaker, 1889, pp. 316–17). By mapping on a six-inch scale, Mr. Selwyn Turner showed that this lower boulder clay was to be found west of Danbury Hill, and my own mapping has added considerably to the recognised outcrop of this deposit. Re-examination of well records shows that a second boulder clay occurs at several localities, and there are other early records of a lower till, as in the Blackwater Valley (Whitaker, etc., 1890). Certainly the till is discontinuous, although it is difficult to be sure that the whole of the outcrop has been mapped. As the till outcrops on valleyside slopes below the Chelmsford gravels and above the London Clay, it is difficult to distinguish from a superficial solifluction deposit, even with the aid of a soil auger.

From the excellent description of the Maldon section (Whitaker, 1889), confirmed by field observation, the Maldon Till is seen to have a matrix consisting largely of London Clay, and fragments of chalk occur only occasionally. This contrast with the Springfield Till appears to be the result of different directions of ice flow, the Maldon ice coming from north or east of north and thus crossing very little chalk to reach the Chelmsford area, while the Springfield ice came from the north-west, across the Chalk outcrop. The chalk content of the Maldon Till increases to the west, and beyond the present area it is as chalky as the Springfield Till, e.g. at Harlow. In that area the course of the Maldon ice must have brought it across the Chalk outcrop to judge by the increase in chalk content.

(e) **Hanningfield Till.** As the dissected sheet of boulder clay which lies to the south of the deposits already described is developed extensively in the parishes of East, West and South Hanningfield, it is called the 'Hanningfield Till'. When seen in deep section the deposit is indistinguishable at sight from the Springfield Till, and both pebble-counts and heavy mineral analyses suggest that there is little difference between their lithologies. Due to the dissection of the deposit, and the nature of the plateau on which it occurs, the till is separated from the sandwich of deposits found north of the Chelmer. Consequently it is not possible to date this till by means of superposition—a frequent difficulty in Pleistocene stratigraphy. In physiographic situation, however, the Hanningfield Till is greatly contrasted with the other drift deposits. It lies on an extensive plateau at about 200 ft. O.D., and does not descend far into the valleys which now dissect this surface. The dissection makes an accurate estimate of the base-level to which this sub-drift surface was graded rather difficult. Evidence from several localities, along the Crouch and Sandon Brook Valleys, suggests the level is about 140–150 ft. O.D. This surface is far higher and older than that on which the tripartite sequence rests, north of the Chelmer. The main valleys of this lower surface were graded to a base-level of about 60 ft. O.D., the clearest evidence for this being the drift base above the estuary at Maldon. The drifts descend below this in several places, notably at Witham in the Blackwater Valley (Woodland, 1943), but these were closed hollows excavated by subglacial meltwater under pressure and were not related to the regional base level of the time. As the Hanningfield Till rests on a surface which is everywhere older than the surface underlying the sandwich of deposits capped by the Springfield Till, it must be an older deposit. In other words, the surface on which the Maldon Till and later deposits rest, was not eroded until *after* the Hanningfield Till was deposited on a land surface graded to a base level nearly one hundred feet higher.

(f) **Danbury Gravels.** The Danbury Gravels have not been mentioned so far and, in fact, their stratigraphical position is not entirely clear. Danbury Hill rises quite sharply above the surrounding drift plateaus to a height of 365 ft. and consists of a core of London Clay almost entirely covered by glacial gravels. These gravels have attracted a good deal of attention as they occur at greater elevations than almost any other glacial gravels in Essex (Salter, 1905; Gregory, 1915, 1922; Solomon, 1935). However, while their elevation above the Chelmsford Gravels is certainly striking, this is largely due to the same rejuvenation that has separated the Hanningfield Till from the Springfield Till altitudinally. In other words, if these gravels were of the same age as the Hanningfield Till, the problem of relative height would be greatly decreased. Two lines of evidence suggest that this is the case. In the first place, the ice sheet which deposited these gravels must have abutted against the hill to at least the maximum height of 365 ft. Only the Hanningfield Till extends as far south of Danbury as this elevation suggests. Secondly, the western face of Danbury Hill, from Danbury Park to Little Baddow, shows a distinct break in the gravels at about 150 ft. O.D., suggesting that below that height the gravels are a more recent deposit. No such break can be traced on the eastern slope of the hill, where the higher gravels merge imperceptibly into the lower gravels. On the other hand, as pits in these eastern gravels show two contrasting types of gravel, it is possible that here the Chelmsford Gravels have been deposited over the older gravels which outcrop at the surface higher up the hill.

Undoubtedly a complicating factor is the great disturbances that have affected the Danbury Gravels. The former Christmas's Pit showed fault-like gravel-clay contacts and, recently, similar structures have been seen at the north end of the Danbury ridge in the Wedlock Green gravel pit (787075). Here the bedding of the gravels dips 70°–80° west over a distance of twenty yards. The ground drops sharply below the pit but it is not easy to envisage landslipping that would cause such a structure, although the steep slopes south of the Chelmer have undoubtedly slipped a good deal.

A more probable explanation seems to be glacial disturbance, and from some anomalous well records elsewhere on the crest of Danbury Hill, it appears that these disturbances affect the whole ridge from Little Baddow to Danbury church (cf. S. V. Wood, 1867, p. 12). There seem to be no grounds for the suggestion that these may be deep-seated structures formed along the line of the Colchester fault.

It is clear that these disturbances are on a large enough scale to jeopardise a subdivision of the Danbury Gravels on the basis of altitude alone. Two other criteria were examined in an attempt to separate the older gravels of Danbury from the Chelmsford Gravels. A large number of heavy mineral analyses were made in an attempt to correlate the boulder clays and the associated gravels. No conclusive results were obtained. An analysis of the gravels alone, based on pebble-counts, was more successful. Usually some 200–300 pebbles were counted and the following groups of pebbles were distinguished:

- (i) Angular and sub-angular flints;
- (ii) Rounded flint pebbles;
- (iii) Quartzites and Quartz pebbles, largely from the Bunter;
- (iv) Other pebbles, including those of far-travelled igneous and sedimentary rocks.

It appears that owing to the low percentages of groups (iii) and (iv) these are of little use in any analysis. The most useful criterion is the percentage of angular and sub-angular flints (group (i)). On this basis the gravels fall into the two groups already suggested on morphological grounds. The Chelmsford Gravels show a content of angular flints lying between 48% and 55%, while the older gravels, including those exposed near the Galleywood pumping station (705039), have a content lying between 57% and 65%. At the Warren Farm Pit (806066) the counts suggest that the upper layers, with 51.8% angular flints, are Chelmsford Gravels and may here overlie the older Danbury Gravels, for the white gravels in the lower part of the pit show 56.9% of angular flints. It should be noted that the Springfield Till has a high percentage of flints (59% at Boreham, if chalk is neglected) so that in the few places where the Chelmsford Gravels are overlain by Springfield Till outwash, the upper gravels show counts comparable with those of the Danbury Gravels. Thus, at the Baddow Hall Pit (736051), the upper layer of dirty gravel, clearly distinguishable from the Chelmsford Gravels below, has 58.5%, while the lower, Chelmsford Gravels (derived from the Maldon Till) have 52% of angular flints.

(g) **Glacial Chronology.** It is not intended here to deal with the difficult problem of inter-regional correlation, but it seems desirable to relate the sequence already described to some known chronology. At present there is no general chronology for East Anglia to which these drift deposits could

TABLE I

Locality	Grid Reference	Age of Gravels	*Percentages of*			
			Ang. & sub.-ang. Flint Pebbles 1	Flint Pebbles 2	Quartzite & Quartz Pebbles 3	Pebbles of Other Rocks 4
Galleywood Pumping Station	705039	Hanningfield Till	61.0	25.0	13.4	0.6
Christmas's Pit	776051	Hanningfield Till	65.0	22.5	12.0	0.4
Warren Farm (lower bed)	806066	Hanningfield Till?	56.9	30.4	12.2	0.5
Hillen's Pit	786051	Hanningfield Till	58.6	30.5	10.3	0.2
Writtle Mill	686061	Chelmsford Gravel	53.0	33.5	12.6	0.9
Warren Farm (upper beds)	806066	Chelmsford Gravel	51.8	36.8	10.9	0.5
Royal Oak Pit	805050	Chelmsford Gravel	48.2	40.0	9.4	2.2
May's Farm	752043	Chelmsford Gravel	52.5	32.0	14.8	0.5
Baddow Hall Pit (lower bed)	736051	Chelmsford Gravel	52.0	34.0	13.4	0.2
Broomfield Pit	720109	Chelmsford Gravel	53.3	28.5	17.0	1.3
Baddow Hall Pit (upper bed)	736051	Outwash from Springfield Till	58.5	24.0	17.6	0.0

be related. The chronology proposed by W. J. Arkell (1943) for the Midland drift deposits has much to recommend it, but it would be difficult to substantiate any correlation in the absence of detailed knowledge of the intervening country. Paradoxically, the clearest analogy is seen in an area even more distant—the North German plain. Recently Professor Woldstedt has summarised the sequence of deposits in that area, although for the present correlation the summary made by Prof. F. E. Zeuner twenty years ago is quite adequate (Zeuner, 1935). As Zeuner pointed out in a later paper (1937), there are many affinities between the two areas, and a general correlation is not difficult. In North Germany a wide belt of Older Drift deposits extends south of the limit of the Newer Drifts. Towards the edge of the Older Drifts it is possible to distinguish deposits of two separate glaciations. The limits of these two glaciations, the Elster and the Saale, run close to one another. Usually the later (Saale) glaciation is the more extensive, but in places the Elster deposits occur south of the Saale drifts. The Elster deposits are very much older than those of the Saale glaciation, for they were separated by the Great Inter-glacial.

In the Chelmsford area the Hanningfield Till, apparently a much older deposit, extends about five miles south of the later Maldon Till and Springfield Till. This distance contrasts with the seventy-five miles to the nearest deposits belonging to the Newer Drift, in north-west Norfolk. On these grounds alone there seems to be a strong case for relating the Hanningfield Till to the Elster glaciation, and the younger 'sandwich' of drifts capped by the Springfield Till, to the Saale glaciation. If this is so, the considerable period of erosion that followed a negative movement of base-level of nearly 100 ft. then falls in the Elster/Saale inter-glacial. As has already been mentioned, this is the Great Inter-glacial, and implies a very great difference in the age of the Hanningfield Till and the later tills.

Confirmation of this is seen in the remarkable contrast in leaching of the Hanningfield Till and the Springfield Till. Normally the Springfield Till is leached free of chalk to a depth of two feet, as in the pit at Boreham (756117). The depth of leaching is not completely constant but on low slopes is nowhere more than four feet. In contrast to this shallow leaching the Hanningfield Till is deeply leached wherever it is preserved over a considerable area. Throughout the parish of East Hanningfield the Till never appears chalky at the surface and this field observation was confirmed by trial pits and auger holes. Thus, an auger hole at Great Claydons, near East Hanningfield (762019) (Fig. 4), passed through 6½ ft. of orange-brown, gritty, pebbly clay before entering chalky pebbly clay which soon became blue-grey in colour. This hole was continued in typical chalky till to a depth of 14 ft., when a large boulder was struck. However, the most convincing evidence for this deep leaching came from the trial pits dug in connection with a subsidiary embankment for the Hanningfield Reservoir

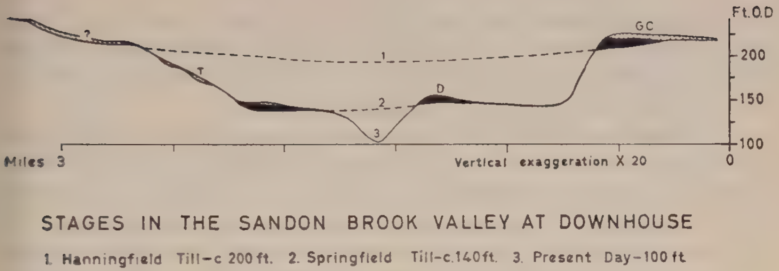

Ft.O.D
200
150
100
0
GC
?
1
T
D
2
3
Miles 3
Vertical exaggeration X 20
STAGES IN THE SANDON BROOK VALLEY AT DOWNHOUSE
1. Hanningfield Till–c 200 ft. 2. Springfield Till–c.140 ft. 3. Present Day–100 ft

Fig. 4. Stages in the Sandon Brook Valley at Downhouse

Key:

Chalky Boulder Clay (black); Leached Boulder Clay (stippled)
T. Tanfield Toy; D. Downhouse; G.C. Great Claydons
(Section based on auger holes)

at 'Fremnells', South Hanningfield (722971). These showed ten to twelve feet of leached material, described as orange sandy clay (with pebbles of flint and quartzite) resting on typical chalky boulder clay (Fig. 3). Since this leaching is considerably greater than that observed on the Springfield Till, a large part of it must have occurred before the deposition of these younger drifts. This implies a considerable period of time between the deposition of the Hanningfield Till and the Springfield Till, which may well be accounted for by the intervening Great Inter-glacial.

The full sequence is summarised in the generalised north–south section (Fig. 2). The tripartite sequence of drifts can be seen to extend a little way south of the Chelmer. There is then a sharp rise in the sub-drift London Clay surface, representing the preceding period of erosion. To the south the Hanningfield Till caps the plateau surface until, with the fall to the Crouch Valley, the limit of the glacial drifts is reached. The sequence may be summarised as follows:

TABLE II

6. Springfield Till	
5. Chelmsford Gravels	SAALE GLACIATION
4. Maldon Till	
3. Period of erosion	ELSTER/SAALE INTER-GLACIAL (Great Inter-glacial)
2. Danbury Gravels	
1. Hanningfield Till	ELSTER GLACIATION

Support for this chronology is found in the paper by Prof. F. E. Zeuner (1937) in which he compared the Pleistocene of East Anglia with that of

Germany. He suggests there may well be two chalky boulder clays in the southern part of East Anglia, and that the older of these would be of the same age as the Norwich Brickearth, i.e. of Elster age, while he relates the Great Chalky Boulder Clay to the Saale glaciation.

(h) **Morphology of the Glacial Deposits.** The subdivision of the glacial drifts into the deposits of two widely separated glaciations explains many contrasts in the areas north and south of the Lower Chelmer. To the south the Hanningfield Till is deeply dissected and the stage of full maturity has almost been reached. Only away from the Sandon Brook and the Wid Valleys is the original till surface still not eroded—and the deep leaching preserved. Around the Galleywood–Billericay ridge, accordant spur-summits on the till show the height to which the drift attained, but the original sheet of boulder clay has now been reduced to small spur-remnants. Here the valleys are proportionately wider than those in the Springfield Till, for the streams were re-initiated on a drift cover at a far earlier stage.

To the north of the Chelmer the contrast is considerable. Here the drifts are thicker and were deposited more recently, with the result that the river valleys are smaller and dissection is only sub-mature. The original surface of the Springfield Till is seen on the series of broad spurs which slope gently south-eastwards. Climbing from the incised valleys of this boulder clay country to the ridge surface, the evenness of the landscape is most impressive. The view links up across the valleys which are hardly noticeable in the succession of uniform, broad plateaus. The eye is reconstructing the former surface of the till, linking up the dissected fragments.

It is usual to ascribe the featureless character of the Older Drift to the great age of the deposits. Although this may well explain the absence of detailed constructional features, the surface of the Springfield Till is flat over such a wide area that some additional cause seems involved. It is possible to reconstruct the former surface of the till by means of generalised contours, and these show that it slopes at between 12 ft. and 15 ft. per mile in a direction within a degree or two of south-east. The surface is almost plane over an area of some 800 square miles. This must be an original feature of this sheet of drift and not simply the result of smoothing by mass movement over a long period of time. The even character of the original till surface would seem to be the result of the chalk scarp to the north-west, lying across the direction of ice advance. The ice-sheet must have accumulated for some time to the north-west of this scarp before it was able to overrun Essex. When more rapid melting of the ice-sheet led to retreat, the general level of the ice must have fallen below the chalk crest while much of the Essex ice remained unmelted. This great sheet of dead ice would then have melted without disturbing the boulder clay.

(i) **Limits of the Glaciations.** The present margin of the Hanningfield Till is largely the result of erosion since its deposition. The boulder clay terminates abruptly on the brink of the Crouch trough, but it appears that only a narrow belt, of a mile or two at most, has been lost by erosion and that the ice never reached far into the Crouch Valley. The original drift margin is preserved east of Woodham Ferrers and around the Galleywood–Billericay ridge. The ice was advancing up a gently sloping surface in this area, which prevented the outward drainage of meltwater and accounts for the almost complete absence of out-wash gravel. These conditions must have led to ponding, of course, and it is possible to identify the main overflow channel for this ponded water. It was exposed in building a subsidiary embankment at the South Hanningfield Reservoir, where a gravel and silt filled channel was seen (Fig. 3). This is in the upper part of the Sandon Brook Valley at Fremnells (722971). Apparently this channel leads up the general line of the present tributary stream, to pass under the boulder clay at Ramsden Heath. The gravel reappears on the south side of this ridge and within the Crouch Valley at the new purification plant (710950) and on the spur north of Crays Hall (705940). It is significant that this valley appears to have joined the Crouch at just below 150 ft. O.D.—the height of the pre-Hanningfield Till base-level.

The margin of the younger drifts to the north differs greatly from the margin of the Hanningfield Till. Advancing over a surface more deeply dissected than that beneath the Hanningfield Till, it extended in quite narrow lobes up the Sandow Brook and Wid Valleys, and down the Chelmer–Blackwater towards Maldon. In the Sandon Brook and Wid Valleys these lobes are now dissected into a series of spur flats within the valleys. The relationship of the lobe of Springfield Till (preserved on the spur at Downhouse in the Sandon Brook Valley) to the Hanningfield Till is shown in Fig. 4. It was only when the ice blocked the Danbury Hill–Tiptree Ridge gap that ponded water sought an overflow route. This can be traced from south of Sandon village (745041) in an easterly direction south of Danbury Hill. The associated gravels lie on the col at 150 ft. but the much lower elevation of the gravels south of Sandon, and the narrow channel that they fill, suggest that at one stage meltwater moved upslope under pressure beneath the ice. The col south of Woodham Mortimer (810040) is a broad one and the escaping water has not cut below 150 ft. O.D. The coincidence in height with the Hanningfield overflow channel seems to be fortuitous, and the lack of erosion at this point suggests that the water escaped eastwards over the lobe of ice that extended through the Maldon gap.

(j) **Evidence for Warping.** In this description heights in feet above Ordnance Datum have been used on several occasions. In all cases these are the present heights of the features concerned, and are not necessarily comparable with heights in other areas at those times. This part of Essex has been subject to gentle downwarping for a considerable period of time

—certainly throughout the glacial period. This warping has had its effect on the morphology of the Essex valleys. Those that trend in a northerly or southerly direction invariably show assymetrical cross-sections. Thus, the south-flowing Chelmer above Chelmsford has a steep eastern valley side; so has the valley of the north-flowing Wid. This asymmetry is not confined to Essex, but is particularly well developed there, and the effect is especially clearly seen in the many valleys cut in the structureless London Clay. This warping is confirmed by the considerable fall in the height of the sub-drift surfaces between Harlow and Chelmsford, as discussed in the second part of this paper.

(k) **Newer Drifts.** The glacial deposits of the Chelmsford area are restricted to the Older Drift. Later glaciations did not reach as far south as these two earlier advances and later deposits are confined to river terraces and patches of loess. The loess is not very widespread and most of it appears to be more recent than the Springfield Till. It is far less importan than it is farther north where, along the Essex–Suffolk border, the thick loess makes mapping of the boulder clays and gravels very difficult. River terraces are not well developed, although two terraces can be traced in all the main valleys. They are quite well developed beyond the limit of the Springfield Till, for there the present river valleys are older and wider an the terraces broader. Within the Springfield Till the valleys are younger an narrower and it is this lack of maturity that has restricted the preservatio of past valley floors as terrace fragments.

The most recent terrace is on the gravel which underlies the presen floodplain of the Lower Blackwater and the Chelmer. This terrace is onl slightly dissected, but typically some 12–15 ft. of gravel underlies th present alluvium. The Blackwater has a well-developed terrace that reache a maximum height of about 30 ft. above alluvium near Witham. It has bee recognised and mapped on the Old Series one-inch geological map (Shee 47 SE). It seems to fall in height downstream, possibly due to warping and only reaches 10 ft. above alluvium at the Chelmer confluence abov Maldon. The Chelmer shows this same terrace, notably on the long ridge lying between the Chelmer and the Sandon Brook at 10–15 ft. above rive level. Here, as in other places, the terrace gravel is indistinguishable fro the underlying Chelmsford Gravels and the terrace can be mapped only o morphological grounds. So far, the third and oldest terrace recognised ha been traced in the Wid Valley only. It lies at some 60–70 ft. above alluviu and the gravels are well exposed in the railway cutting at Widford (696050 where they rest on the Springfield Till.

(l) **Summary of Part I.** The Chelmsford area, like other areas at th southern limit of glaciation of this country, shows a complex sequence o deposits. Due to the alternation of deposition and erosion in Pleistocen times, the principle of superposition is inadequate to place these drifts i their correct chronological order, so other techniques must be used. As a result of the considerable area occupied by the Hanningfield Till, the morphological results are well substantiated and the chronology outlined here seems to be the only one which will fit with all the evidence available. As in all work on glacial deposits, the test is not so much whether each item in the evidence will stand alone, but whether the analysis that is made presents a coherent account of the geological and morphological processes which have affected the area in the last 500,000 years.

REFERENCES

ARKELL, W. J. 1943. The Pleistocene Rocks at Trebertherick Point, North Cornwall. *Proc. Geol. Ass., Lond.*, **54,** 141–70.

BOSWELL, P. G. H. 1914. On the Occurrence of the North Sea Drift. *Proc. Geol. Ass., Lond.*, **25,** 121.

GREGORY, J. W. 1915. The Danbury Gravels. *Geol. Mag.*, **52,** 529–37.

————. 1922. *Evolution of the Essex Rivers.* Colchester.

HARMER, F. W. 1904. The Great Eastern Glacier. *Geol. Mag.*, **41,** 509.

————. 1909. The Pleistocene Period in the Eastern Counties of England, in: *Geology in the Field, Geol. Assoc. Jubilee Volume.*

SALTER, A. E. 1905. On the Superficial Deposits of Central and parts of south England. *Proc. Geol. Ass., Lond.*, **19,** 1.

SOLOMON, J. D. 1935. On the Westleton Series. *Quart. J. geol. Soc. Lond.*, **91,** 216–38.

TURNER, J. S. 1937. Field Meeting at Danbury, Essex. *Proc. Geol. Ass., Lond.*, **48,** 160–1.

WHITAKER, W. 1889. The Geology of London and Part of the Thames Valley. *Mem. geol. Surv. U.K.*

————. 1890. Explanation of Sheet 47 of the Map (One Inch) of the Geological Survey. *Mem. geol. Surv. U.K.*

WOLDSTEDT, P. 1950. *Norddeutschland im Eiszeitalter.*

WOOD, S. V. (Jnr.). 1865. *Remarks in Explanation of a Map of the Upper Tertiaries*, etc.

————. 1867. 'A Memoir in explanation of the glacial and post-glacial beds, etc.' Manuscript in Library, Geol. Soc., London.

WOODLAND, A. W. 1943. Water supply of Cambridge–Ipswich District. Well catalogues for New Series One Inch sheet 241 and areas. *Geol. Survey Wartime Pamphlet*, **20,** 9.

ZEUNER, F. E. 1935. The Glacial Chronology of Central Europe. *Geol. Mag.*, **72.**

————. 1937. A comparison of the Pleistocene of East Anglia with that of Germany. *Proc. prehist. Soc. London*, 136–57.

Part 2. THE DRIFT GEOLOGY OF HARLOW NEW TOWN

(a) **Introduction.** The drift sequence of the Harlow New Town area compares very closely with that described for the area around Chelmsford. Not only are deposits of two glaciations present, but at Harlow, as at Chelmsford, the later of these is composite and consists of two boulder clays separated by glacial gravels. In addition, the morphological relationship of these two sets of deposits is very similar, for at Harlow the younger deposits lie within the Stort Valley (though generally above the present valley floor) while the older deposits cap the high ridge to the south, much as the Hanningfield Till caps the plateau south of the River Chelmer. But the Harlow evidence does more than confirm the Chelmsford sequence. In its critical relationship to the pre-glacial Thames Valley it provides an outline chronology for the glacial history of the lower Thames.

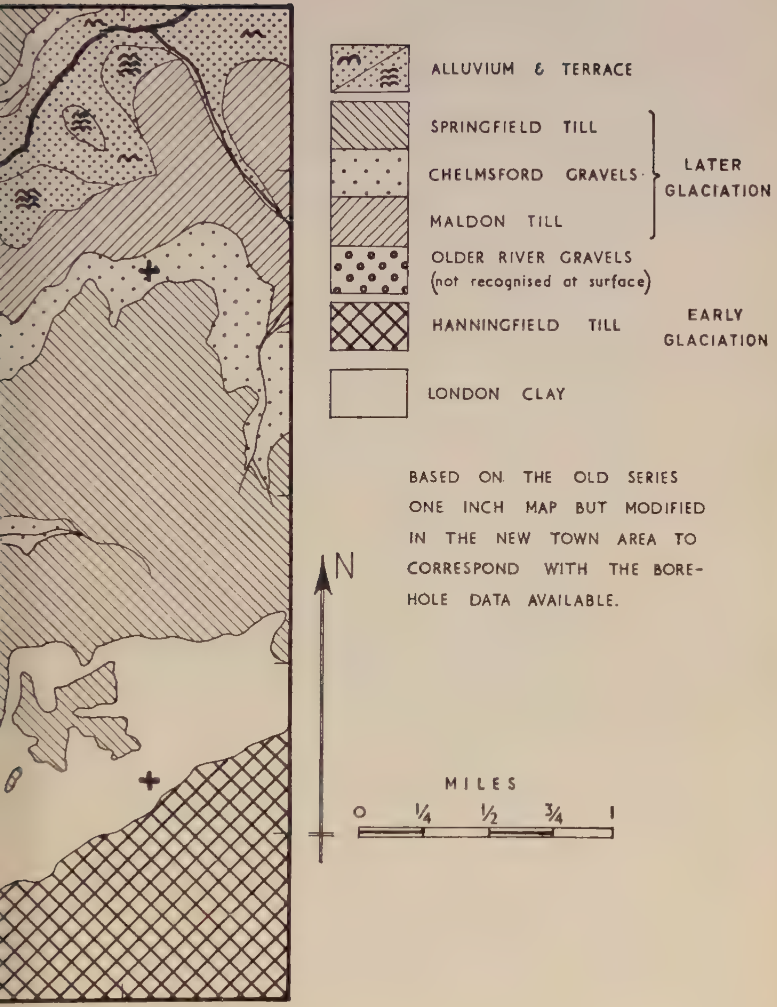
Harlow New Town lies on the south side of the Stort Valley about half-way between the valley bend at Sawbridgeworth and the confluence with the River Lea. The ground rises in two stages to the ridge of Epping Long Green which forms the southern boundary of the area. From Figure 5(a) it will be seen that the broad step between these two slopes is dissected by the Canons Brook and its two tributaries to form a low ridge, broken where the drainage escapes northwards to the River Stort.

(b) **Drift Geology.** The geological map (Fig. 5(b)) shows that much of this ground is drift covered, and the London Clay outcrops only on the sides of the Canons Brook Valley and on the slopes leading up to Epping Long Green. The variations in the drifts have necessitated a very large amount of boring in the New Town Area and the information from these holes was readily made available by the New Town Corporation. The programme is not yet complete, particularly in the west of the area, but for much of the New Town, a complete description of the drift sequence is possible on the basis of these borehole data. The holes vary from rarely less than 10 ft. to a maximum of 60 ft. in depth, and altogether nearly 2000 borings, with an aggregate depth of 25,000 ft., are utilised in the accompanying maps. The first holes were surveyed instrumentally by the New Town Corporation to determine their altitudes, but for most of the holes the heights have been extracted from the special Ordnance Survey maps of the New Town area, which have surveyed ten-foot contours and interpolated five-foot contours.

The sequence of drift deposits in Harlow is directly comparable with that already described for the area around Chelmsford (Fig. 6). The comparison is very close, while the great volume of borehole data gives a much more detailed picture of the stratigraphy of the deposits and, in particular, the form of the sub-drift surface on the London Clay. The tripartite sequence of the Chelmsford area is clearly recognisable in Harlow. It was completely penetrated by a deep bore at the town centre (447101) which passed through the following strata:

	ft.
4. Chalky clay with stones (Springfield Till)	0–13
3. Sand and gravel, some chalk (Chelmsford Gravel)	14–41
2. Chalky clay and stones (Maldon Till)	42–56
1. Gravel, some sand—not bottomed (unrepresented in the Chelmsford area)	57–60

It will be seen that the two tills and the intervening gravel appear but that, in addition, a second gravel occurs beneath the Maldon Till. Although this hole did not reach the London Clay, there is every indication that it ended



BASED ON THE OLD SERIES ONE INCH MAP BUT MODIFIED IN THE NEW TOWN AREA TO CORRESPOND WITH THE BOREHOLE DATA AVAILABLE.

[*To face p.* 14

only a foot or two from the base of the gravel, and that this lower gravel is not very thick. This gravel, and the surface on which it rests, will be referred to later. These younger drifts die out to the south against the Epping Long Green ridge, and a slope of London Clay rises nearly 100 ft. to the top of the ridge which is capped by boulder clay. It is suggested that this high-level boulder clay is the local equivalent of the Hanningfield Till. It shows comparable topographic expression, although the depth of leaching shown in the Chelmsford area is not normally seen here. No doubt this is due to the ridge being narrow, so that since the Great Inter-glacial erosion has removed the ten feet or so of leached till that must have formed during that time. In the Chelmsford area the Hanningfield Till shows deep leaching only where wide plateau-like areas are preserved; elsewhere mass-movement has removed the leached zone. Some confirmation of this is seen in the spread of chalk-free pebbly clay, some 3 ft. deep, that covers much of the London Clay slope north of the Epping Long Green ridge.

(c) **Springfield Till.** The Springfield Till occupies all the higher ground north of the Stort and slopes down towards the river with extensive outliers in the New Town area, much as smaller outliers lie south of the Chelmer below Chelmsford (Fig. 5 and Fig. 6). South of the Stort the surface of the Springfield Till is very level, rising to 250 ft. in the west, at Oldhouse Lane (Western Industrial Estate), to 255 ft. in Markhall Wood in the east, and to 245 ft. north-west of the Town Centre (Figs. 5(a) and 7). Between these points the ridge does not fall below 230 ft. except where it is broken by the Canons Brook. Over most of this area the Springfield Till is only about 20 ft. thick and consists of a sheet of chalky boulder clay with flint and quartzite pebbles. It is only slightly leached, and the many bores show only a foot or two of chalk-free subsoil. Correlation across the Stort Valley is quite straightforward as in the gravel pit at Pole Hole (457128) where the three drifts are well exposed, and lie at much the same levels as they appear, in the borehole records, only a mile to the south on the other side of the River Stort.

(d) **Chelmsford Gravels.** The Chelmsford Gravels are well exposed in several gravel pits besides being clearly recognisable in the borehole records. They rest on the Maldon Till, and over much of the New Town area the base of the gravels is between 180 ft. and 200 ft., sloping gently towards the River Stort (Fig. 7). The upper surface is much less even, and rises beneath the Parndon Hall–Markhall Wood ridge to 230 ft. O.D. Thus the gravels vary in thickness from only a few feet to a probable maximum of about 43 ft. north-west of the Town Centre (Fig. 5(a)). The maximum thickness actually penetrated by a borehole is 32 ft., at 448103. In the boreholes around the Town Centre the Chelmsford Gravels may be subdivided lithologically. Normally the upper part of the deposit is described as sand and gravel and is about 15 ft. thick; the lower 15 ft. is a much finer deposit, described as sand or running sand and often contains chalk. This lower sand is well seen in the pits at Netteswell Cross (455106) and is overlain by the coarser material which is less well sorted and contains clay bands. The lowest beds above the Maldon Till are frequently described as silty clay, as in the bores south of the Old Town of Harlow and by the Stow (472112 and 460107). These records and sections suggest that much of the Chelmsford Gravels of the Harlow area may have been deposited in standing water, with the less well sorted gravels towards the top of the deposits indicating the advance of the Springfield ice. This evidence for what was probably a pro-glacial lake is similar to deposits known from near Ware and Hertford. The Memoir for the Hertford geological sheet describes laminated clay in the Ware brick-pit (Sherlock & Pocock, 1924, p. 47) while Barrow noted fine loamy sand with two seams of laminated clay at Hertford (Barrow, 1910, p. 170). In both cases these deposits occupied a similar position to the deposits at Harlow, i.e. near the base of the gravel occurring between two boulder clays (Sherlock & Pocock, 1924).

(e) **Maldon Till and Underlying Gravel.** The Maldon Till appears in a few deep bores which penetrate the overlying gravels and till, and can be traced in more detail where it outcrops on the valley sides, as from the Canons Brook Valley round to Burnt Mill, and again under the Eastern Industrial Estate (see map, Fig. 5(a)) on the southern slopes of the Stort Valley. Whereas neither of the overlying deposits can be traced down the valley slopes below about 170 ft., the base of the Maldon Till drops sharply towards both the Stort Valley and the Canons Brook. It cannot be traced below 120–130 ft. O.D. (Fig. 7), and it appears that the sub-alluvial channel of the Stort (descending to 100 ft. at the Canons Brook confluence) was cut after the deposition of the Maldon Till. There is no evidence of any fall in the base of the Till along the line of the Todd Brook and it seems that this tributary of the Canons Brook has developed since the sandwich of drifts was deposited. In the borehole records the Till is described as a chalky clay with stones (flints and quartzites) and this is confirmed by temporary sections in the deposit. Unlike the Maldon Till near Chelmsford, the deposit is, if anything, richer in chalk than the Springfield Till.

The gravel underlying the Maldon Till at Harlow forms a thin, sandy and apparently continuous deposit north of the Parndon and Todd Brooks. Here it rests on a wide flat cut in the London Clay at a little above 160 ft. The origin of this deposit will be discussed in a later paragraph. It appears to mantle the slopes which fall to the Canons Brook and Stort Valleys, but variations in thickness and lithology make interpretation of the boreholes on these steep slopes very difficult. Gravel also underlies the present alluvium, usually to a depth of fifteen feet. This gravel is not overlain by the Maldon Till and, on morphological grounds, is probably considerably younger than the Till. If this is so, two different gravels are represented in the valley slopes, but they are inseparable on lithological grounds.

(f) **Sub-drift Surface.** The sub-drift surface on the London Clay can be mapped with considerable accuracy with the aid of the Harlow boreholes (Fig. 8). From a height of about 330 ft. on the Epping Long Green ridge, the surface falls to the 170 ft. contour as a steep, dissected slope. Over much of this area the London Clay is at the surface, but below 260 ft. many of the spurs are composed of chalky boulder clay. As the surface level on these spurs rises to the same height as the Parndon Hall–Markhall Wood ridge, the boulder clay is presumed to be the Springfield Till. Under much of the New Town, the sub-drift surface is an extensive bench, more than a mile wide in the west and narrowing to the east. The bench lies between 160 ft. and 165 ft. O.D., and is clearly a pre-Maldon Till valley stage of considerable importance. The River Stort and the Canons Brook are incised below this level and although some of this erosion is later than the Springfield Till, the disposition of the Maldon Till suggests that some of this rejuvenation occurred before the Maldon ice-sheet reached the area.

(g) **Correlation with the River Thames.** Prof. S. W. Wooldridge has shown (Saner & Wooldridge, 1929; Wooldridge, 1955) that the pre-glacial Thames followed a route which led eastwards from the Lea Valley at Hertford through a valley now buried beneath glacial drifts towards Chelmsford, whence it reached the sea either by the Blackwater or Stour estuaries. It is clear that the valley stage shown in the sub-drift surface at Harlow must be the floor of the Thames before the advance of the Maldon ice-sheet. The sub-drift surface of the Vale of St. Albans, excavated by a tributary to the Thames before the advance of the Maldon ice-sheet, slopes eastwards from about 200 ft. towards the level seen at Harlow, and the Thames at this time followed what has been called the Middlesex loopway, now blocked by the boulder clay lobe at Finchley (Wooldridge, 1938). At this period the Thames formed the Lower Gravel Train, and it seems likely that the lower gravel at Harlow, resting on this old valley floor, is Thames gravel belonging to the Lower Gravel Train aggradation. It has already been suggested that the Lower Gravel Train, if projected eastwards, would slope to about 170 ft. O.D. at Broxbourne (Wooldridge & Linton, 1955, p. 136), a figure remarkably near that revealed by the Harlow bores.

When the chronologies of the Harlow and the Middle Thames areas are compared, the correlation is seen to be good. The Chiltern drift (Barrow, 1919; Wooldridge, 1938; Wooldridge & Linton, 1955), lying above 350 ft. O.D., is the western equivalent of the Hanningfield Till of Epping Long Green, with its base at 330 ft. O.D. The Chiltern drift shows considerable evidence of deep leaching where it is preserved on level surfaces—notably near Ayot Green (224143). This early ice-sheet diverted the Thames from its high-level route along the line of the Vale of St. Albans to the Middlesex loopway, but the course through Harlow and Chelmsford was maintained through the succeeding inter-glacial. The tripartite drift sequence, so well seen at Harlow as at Chelmsford, is exactly matched in the Vale of St. Albans where two boulder clays are separated by a sheet of gravel, and also between these places, as at Ware (*Summ. Progr. geol. Surv., Lond.*, 1915, p. 31; 1920, p. 7). The dissected surface of this lobe of the Springfield Till can be traced westwards from Harlow to the Vale of St. Albans, where the surface rises gently to about 290 ft. along the centre of the lobe, and in places the margins rise a little above the 300 ft. contour. This rise is gentle and occurs on the boulder clay, which contrasts with the abrupt drift-free rise on London Clay to the Hanningfield Till of Epping Long Green. In any case, the surface is still at least 50 ft. below the base of the early Chiltern drift.

(h) **Effect of Warping.** In the description of the Chelmsford area it was suggested that the warping which occurred in the early Pleistocene has continued since the deposition of the Springfield Till. This is confirmed by a comparison of the sub-drift surfaces of Harlow and Chelmsford. The level below the Hanningfield Till cannot be fixed with accuracy at Harlow but was at about 300 ft. This compares with 140 ft. at Chelmsford. Similarly, the surface below the Maldon Till at 160 ft. at Harlow compares with the base level of 60 ft. found in the Chelmsford region. In each case part of the difference is accounted for by the gradient of the River Thames of the time over the twenty-five miles from Harlow to Maldon. As a result it is not possible to determine the amount of warping since these two dates, but since the Hanningfield glaciation, it can hardly have been more than 100 ft., and may be rather less than this. The amount of warping since the deposition of the Springfield Till appears to be less than 50 ft.

(i) **Conclusion.** Although much detailed work remains to be done, the major stages in the glaciation of the Lower Thames Valley now seem to be clear. Evidence from three separate areas along the mid-Essex route of the pre-glacial Thames shows a common pattern of glaciation with an early, high-level drift, followed by a later double ice advance. The drifts of this later advance block the early valleys which have been only partially re-excavated. Thus, over a large part of Essex the surface of the Springfield Till is undissected, and even in areas such as the Vale of St. Albans and Harlow, where the larger rivers have been more active, the original surface of the till can be clearly seen. Many of the Essex rivers follow their pre-glacial courses although flowing in relatively narrow valleys excavated in the later drifts; others were initiated on new lines on the surface of the Springfield Till. Of the last, the River Roding, which crosses the buried Thames Valley at right angles, is one of the most important. The Thames was not diverted from its mid-Essex course until the advance of the Maldon ice-sheet, so that the present work confirms that the present Thames Valley

below the Brent confluence is later in age than the first ice advance of the 'Chalky Boulder Clay glaciation' (Wooldridge & Linton, 1955, pp. 134–5).

In the analysis and interpretation of these Essex drifts considerable stress has been laid on their morphological positions. The area has been affected by erosion and deposition alternately, in response to the advance and retreat of ice-sheets and to the associated movements of sea-level. The present pattern is that of a polycyclic landscape in which the surfaces are overlain by drift deposits of differing ages and character. The local summit plane at 300–400 ft. bears the pebble gravel a little below which is an extensive surface, largely above 200 ft., covered by the Hanningfield Till. The younger drifts rest on a still lower surface, cut in relation to a later base level. Within the area of the Springfield Till the landscape is submature with narrow valleys and wide, undissected ridges and it is only to the south that the terrace stages of the later cycle are widely developed.

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REFERENCES

BARROW, G. 1910. Excursion to Hertingfordbury and Hertford. *Proc. Geol. Ass., Lond.*, **21,** 170.

———. 1919. Some future work for the Geologists' Association. *Proc. Geol. Ass., Lond.*, **30,** 36–48.

SANER, B. R. & S. W. WOOLDRIDGE. 1929. River-development in Essex. *Essex Nat.*, **12,** 244.

SHERLOCK, R. L. & R. W. POCOCK. 1924. The Geology of the Country around Hertford. *Mem. geol. Surv. U.K.*

WOOLDRIDGE, S. W. 1938. The glaciation of the London Basin and the Evolution of the Lower Thames drainage system. *Quart. J. geol. Soc. Lond.*, **94,** 627–67.

——— & H. C. K. HENDERSON. 1955. Some aspects of the physiography of the eastern part of the London Basin. *Institute of British Geographers*, Pub. No. 21, 19–31.

——— & D. L. LINTON. 1955. *Structure, Surface and Drainage in South-east England.*

———. 1915. *Summ. Progr. geol. Surv., Lond.*, 1914.

———. 1920. *Summ. Progr. geol. Surv., Lond.*, 1920.

DISCUSSION

DR. J. D. SOLOMON congratulated the Author on tackling this very difficult area, and on his clear presentation of his results. Having, however, had the opportunity of examining the heavy mineral assemblages from samples collected by the Author, he found himself quite unable to accept the interpretation put forward in the paper.

The Hanningfield boulder clay contained the assemblage that he had found to be characteristic of *all* 'Gipping' type boulder clays, from Suffolk and Essex to Warwickshire. Garnet was about twenty per cent, and there were appreciable amounts (about five per cent) of hornblende and epidote. Now if this boulder clay had been widespread, it must have contributed largely to the 'Mid-glacial' sands and gravels; but in point of fact these gravels, whether on the Danbury ridge or elsewhere, contained no more than a trace of these minerals except occasionally in the uppermost layers, where later glacial contamination was possible.

Their pebble content also negatived their correlation with any chalky boulder clay. They were packed with Tertiary type flint cobbles, vein quartz, up to ten inches in diameter, and also contained Lower Greensand chert and pebbles of a grey quartzite not found in Bunter bearing drifts in East Anglia or on the Chilterns. It seemed hardly possible that these materials could be derived from a northerly or north-westerly source, as the boulder clay certainly *was*.

The fact was that there were *two* distinct gravels—one the genuine 'Mid-glacial' or 'Westleton', which outcropped on the *sides* of the valleys and pre-dated all the chalky boulder clays, and a later one which occurred only *in* the valleys and formed the middle of the sandwich described by the Author. The later gravels, here represented by the Chelmsford Gravels, invariably contained a significant proportion of chalky boulder clay minerals.

The speaker welcomed the push-moraine interpretation of the Danbury Ridge; he himself had been misled by inadequate exposures into postulating a tectonic origin for the structures. This latter view was certainly unsound.

He did not consider that morphological evidence was generally valid for dating boulder clays, which could clearly blanket hill and valley alike. With regard to the leaching of the Hanningfield clay, he had been struck by the almost stoneless nature of the soil on the plateau, and wondered if the leached layer, which the Author admitted was not present everywhere, was in fact a brickearth deposited in hollows in the boulder clay surface, like the famous deposits at Hoxne. He himself was inclined to co-relate the Hanningfield and Springfield boulder clays, and to regard all three as belonging to the same major glaciation—presumably the so-called 'Riss-Saale'.

MR. P. EVANS asked if the Author had obtained any evidence of the orientation of pebbles in the different boulder clays, and whether Dr. Solomon could indicate what were the other changes in the heavy mineral suite when garnet was rare.

DR. J. D. SOLOMON in a written reply to the point raised by Mr. P. Evans states that where garnet was rare, there was a corresponding increase in zircon, tourmaline and staurolite. The assemblage was then the impoverished one familiar in the 'pebble-gravels' in the London area.

MR. K. M. CLAYTON in replying, first referred to the interpretation of the evidence of the heavy mineral residues of the various deposits. Dr. Solomon had suggested that much of the Chelmsford Gravels was really of greater age, and of Westleton type. He had suggested that the main evidence for this was the absence of garnet from all the gravels, despite its presence in all three of the boulder clays recognised in this paper. Geological mapping had shown that in places the Chelmsford Gravels were preserved between the Maldon and Springfield Tills, a point first made by Mr. Selwyn Turner. Yet although both the Maldon and the Springfield Till were rich in garnet, none occurred in the intervening gravel. This strongly suggested that garnet once in the gravel had been lost, presumably by conversion to chlorite or kindred alteration products. It was true that the Chelmsford Gravels represented an influx of Thames material in addition to the outwash from the Maldon ice-sheet, but there were no grounds for equating the Chelmsford Gravels with the marine Westleton deposits of Suffolk.

The leached layer on the Hanningfield Till is inevitably lost in places, for its survival depends on an absence of erosion since the Great Interglacial. It is quite definitely a leached layer and not a brickearth or other distinct deposit, for it has all the constituents of the underlying till apart from the pebbles and particles of chalk.

In reply to Mr. Evans, the Author said that West and Donner had measured the orientation on the Springfield Till to the west of Chelmsford, where it was north–south.

Measurements had been made by the Author at Harlow, but he was not prepared to place much reliance on the results. They showed some differences in the orientation of the Maldon and Springfield Tills. There are no permanent exposures in the Hanningfield Till, none of the orientations measured by West and Donner refers to this till, and only one, rather obscure, measurement has been obtained by the Author so far.

Dr. Solomon had raised the fundamental point of the validity of morphological evidence for the dating of boulder clays. While such methods might be of little value in some areas, they were of particular value along the limits of glaciated areas. In South Essex, as the Author had tried to demonstrate, the ice-sheets did not blanket hill and valley alike, but fingered out along the valleys in quite narrow lobes. At their margin the ice-sheets were closely controlled by the relief of the ground over which they advanced. The Author had tried to show that the Hanningfield Till had not advanced over the same land surface as that invaded by the Maldon and the Springfield Tills. It seemed that the morphological position of the marginal lobes of the till-sheets offered the best method of differentiating between them.

In conclusion the Author wished to thank the two speakers for the points they had raised and to thank the President and Members for their kind reception of the paper.

Field Meeting at Danbury Hill, near Chelmsford, Essex

24 July 1955

Report by the Director: K. M. CLAYTON

Received 20 September 1955

SOME FIFTEEN members and friends met at Chelmsford Station at 11.30 a.m.

The Director explained that although the principal object of the excursion was to visit some new sections in the gravels covering Danbury Hill, he also hoped to show something of the glacial succession in the area as a basis for discussing the probable age of the Danbury Gravels. By mapping the area on a scale of six inches to the mile it had become apparent that the simple division of the drifts of the area into the boulder clays and gravels of one glaciation was inadequate. Although all the glacial deposits undoubtedly belong to the Older Drift, they may be subdivided into the deposits of two distinct glaciations. As the second glaciation was composite and is represented by two boulder clays, the problem of correlating the glacial gravels of Danbury with one or more of these ice advances becomes very complex.

The first stop was made outside the Baddow Hall pit (52/736052), visited by the Association on the last field meeting in this area in 1936. This pit, which is now being filled in, shows some forty feet of glacial gravels, probably resting on London Clay. On the previous visit Mr. Selwyn Turner pointed out (Turner, 1937) that careful mapping to the east of the pit showed that these gravels were sandwiched between two boulder clays.

This is fully confirmed by the remapping of the area. The lower boulder clay is discontinuous and very difficult to map, but it is seen in several localities, including the section exposed in the Maldon railway cutting (52/841065), fully described by Whitaker (1889) in the Survey Memoir. The boulder clay above the gravels only occurs in small patches south of the River Chelmer, but to the north it becomes the extensive sheet of chalky boulder clay described by Harmer as the product of his Great Eastern glacier.

In order to avoid as far as possible problems of correlation, the Director suggested local terms for this tripartite sequence: Maldon Till (the oldest), Chelmsford Gravels and Great Eastern Till. These drifts are all assigned to Arkell's Catuvellaunian glaciation, as the Maldon Till shows no evidence of more than an early advance of the Great Eastern ice sheet.

The party then drove to the plateau at East Hanningfield (52/765091), where a chocolate brown pebbly clay was seen, thrown up by drainage operations. The Director explained that an auger hole made in this deposit had proved six feet six inches of leached pebbly clay lying above normal blue-grey chalky boulder clay. The boulder clay had not been bottomed at fourteen feet where the auger struck a large stone. Other evidence for deep leaching in this boulder clay came from trial pits in the upper part of the new reservoir at South Hanningfield which showed eleven feet of leaching. Such leaching is far greater than that seen on the Great Eastern Till where it only reaches a depth of about two feet. In addition the drift at East Hanningfield lies on a surface of London Clay that was graded to a sea level at about 150 feet O.D., in contrast the Catuvellaunian drifts descend into the valleys to about fifty feet O.D. under normal circumstances. This suggests that the Hanningfield Till is a far older deposit and of Berrocian age. The extent of this Berrocian Till was seen in a view south from above the Cricketers Inn at Danbury Common (52/779049). The till reaches south to the northern edge of the Crouch Valley where the original limit has been lost as a result of erosion. To the south-east, however, the original limit of glaciation can be traced with the aid of a hand auger, although the character of the plateau does not change in the passage from the leached Hanningfield Till to the London Clay.

After having lunch in the sun outside the Cricketers Inn, the party proceeded to the main business of the day. The first of the sections on Danbury Hill to be visited was at the Royal Oak pit, an extensive working some fifteen to twenty feet deep. The best sections at the time of the visit were in the north-east corner of the workings and just south of Thrift Wood (52/805051). Boreholes here have proved that the fifteen feet of gravels worked in the pit lie on six to seven feet of sandy clay or brickearth, underlain by more than forty feet of gravel, which has not been bottomed. The gravels on Danbury frequently show thicknesses of this order.

Some fifty to sixty feet of gravels are exposed at the Warren Farm pit (52/805066), while at one time the Wedlock Green pit (52/786075) showed 100 feet of sands and gravels; in neither case was the underlying London Clay seen.

In contrast the Chelmsford Gravels are normally thirty to forty feet thick. As they also occur at much lower levels it seems that correlation of the Chelmsford and Danbury Gravels is unlikely. The gravels of Danbury Hill rise to the highest point at 365 feet O.D. and the Director suggested that the ice sheet that stood against the hill at this height would be likely to extend some distance to the south. The only time that this occurred was when the Berrocian ice deposited the Hanningfield Till as far south as the Crouch Valley. This suggests that the Danbury Gravels and the Hanningfield Till are contemporaneous, and that the Danbury Gravels are outwash gravels of the Berrocian ice sheet.

The Royal Oak pit (52/805050) provided a good selection of erratics; angular and rounded flints predominate, while Bunter quartzites and quartz together form about fifteen per cent of the pebbles. Other rocks found normally forming less than one per cent of the pebbles were a fragment of red conglomerate, a brecciated black slate and a block of puddingstone. Some discussion arose as to how many of these rocks were derived from the Bunter pebble beds. In particular, Dr. Solomon regarded the proportion of the pale-coloured quartzites as too high for all of them to have been derived from the Bunter pebble beds.

The second pit to be visited, at Warren Farm, Woodham Walter (52/805066), showed a deeper section. The upper part showed orange-brown gravels with variable bedding that seemed to correlate with those seen in the Royal Oak pit. In part of the Warren Farm pit these upper gravels are completely missing and are replaced by brickearth in what appears to be the cross-section of a former river-bed. The lowest part of the pit cuts down through silty clays to expose white sands and gravels. These may be appreciably earlier in age than the overlying deposits; certainly the greater abundance of the rarer erratics in them suggested that it might be possible to differentiate the two deposits on lithological grounds. Among erratics found in this lower gravel was a small rolled pebble of silicified oolite and a fragment of Lower Greensand chert.

The last pit visited was at Wedlock Green, where only the western pit (52/786075) was seen as time was short. The structure here is complex and the gravels have clearly undergone considerable disturbance. A gravel-clay contact in the extreme west of the pit is practically vertical, and the bedding in the gravel east of this contact remains between seventy and eighty degrees for some thirty yards of the face. Beyond this contortions have been seen in the beds on previous visits but these were now obscured by rainwash. Where the face was still clear on the east side of this section, the gravel bedding was more normal and dipped slightly to the north. A sketch of the full section is shown in Fig. 1.

The clay seen was probably not London Clay *in situ* but a glacial clay, possibly deposited in a pro-glacial lake, and certainly consisting very largely of redeposited London Clay. The evidence for this is in the nature of the gravel-clay contact, at which a thin band of gravel separates a similar thick band of clay from the main mass of the clay. This indicates that for a short time the earlier conditions of deposition reasserted themselves, and that the clay is of much the same age as the gravel. This sequence at the gravel-clay junction is seen both in the west of the pit where the bedding is nearly vertical and some sixty yards to the east where the gravel overlies the clay with a nearly horizontal junction. In working gravel in this pit, clay has been met with at many unexpected levels, while in a few places the gravel has not been bottomed.

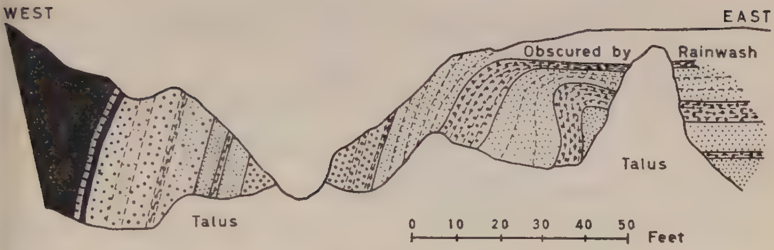

Fig. 1. Section on north face of the West Pit at Wedlock Green, Little Baddow (52/785075)

Key: Clay, black; sand, fine stipple; gravels, coarse stipple. The bedding of the gravels is indicated

At the time of the Association's visit the west pit had not been worked for some months and was some sixty feet deep, while on a previous visit a composite face of 100 feet had been seen without the base of the sands and gravels being exposed.

The Director referred to the many records of complex structure on Danbury Hill, particularly in the former Christmas's pit (52/777050) below the church near Eve's Corner. Attempts had been made to explain these as structural disturbances, along the line of the mid-Essex fault, or as large-scale landslips—an explanation favoured by the Director. One or two members of the party suggested that Danbury Hill might in part be a *Stauchmoräne*, with the disturbances resulting from glacial shoving; certainly the possibility must be borne in mind.

The party had tea at Eve's Corner, after which the President, Dr. L. R. Cox, proposed a vote of thanks to the Director. The party then returned to Chelmsford for the London train.

REFERENCES

Arkell, W. J. 1943. The Pleistocene Rocks at Trebertherwick Point, North Cornwall. *Proc. Geol. Ass., Lond.*, **54**, 141–70.

Gregory, J. W. 1915. The Danbury Gravels. *Geol. Mag.* (6), **2**, 529–38.

Salter, A. E. 1906. Excursion to Danbury and Little Baddow. *Proc. Geol. Ass., Lond.*, **19**, 455.

Solomon, J. D. 1935. The Westleton Series of East Anglia, its age, distribution and relations. *Quart. J. geol. Soc. Lond.*, **41**, 216–33.

Turner, J. S. 1937. Field Meeting at Danbury, Essex. *Proc. Geol. Ass., Lond.*, **48**, 160.

Whitaker, W. 1889. The Geology of London and part of the Thames Valley. *Mem. geol. Surv. U.K.*, 316–17.

Escarpment Dry Valleys Near Pegsdon, Hertfordshire

by B. W. SPARKS and W. V. LEWIS

Received 15 February 1956; Read 1 February 1957

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ABSTRACT: The short, steep-sided, blunt-ended dry valleys in the chalk escarpment between Hitchin and Luton are discussed and attributed to spring sapping. Post-glacial deposits in the valleys are described and approximately dated by the mollusca contained in them.

1. INTRODUCTION

THE MAJORITY of the dry valleys on the dip slopes of the chalk lands of England are characterised by fairly gentle slopes and subdued forms. Contrasting with these, certain valleys in the chalk escarpments present steep slopes and youthful appearances, as though they belonged to a later phase of erosion. Such valleys are usually short, steep-sided and blunt-ended; often they possess flat floors and sometimes marked right-angled bends. Valleys of this type occur at the north-eastern end of the Chilterns, and it is with this group that the present paper is particularly concerned. A preliminary account of these valleys has been given by one of us (Lewis, 1949).

2. THE FORM OF THE VALLEYS

The three valleys between Barton in the Clay and Pegsdon, which we will refer to as the Barton, Ravensburgh and Pegsdon valleys (Fig. 1), possess certain features in common and others peculiar to one or two of them.

All the valleys, with the exception of the uppermost parts of the Ravensburgh Valley, have steep side-slopes, in many places reaching thirty degrees. The breaks of slope at both the top and bottom of the sides are usually marked angles and not the normal smooth curves of chalk landscapes. Above the upper break of slope the crest of the escarpment is

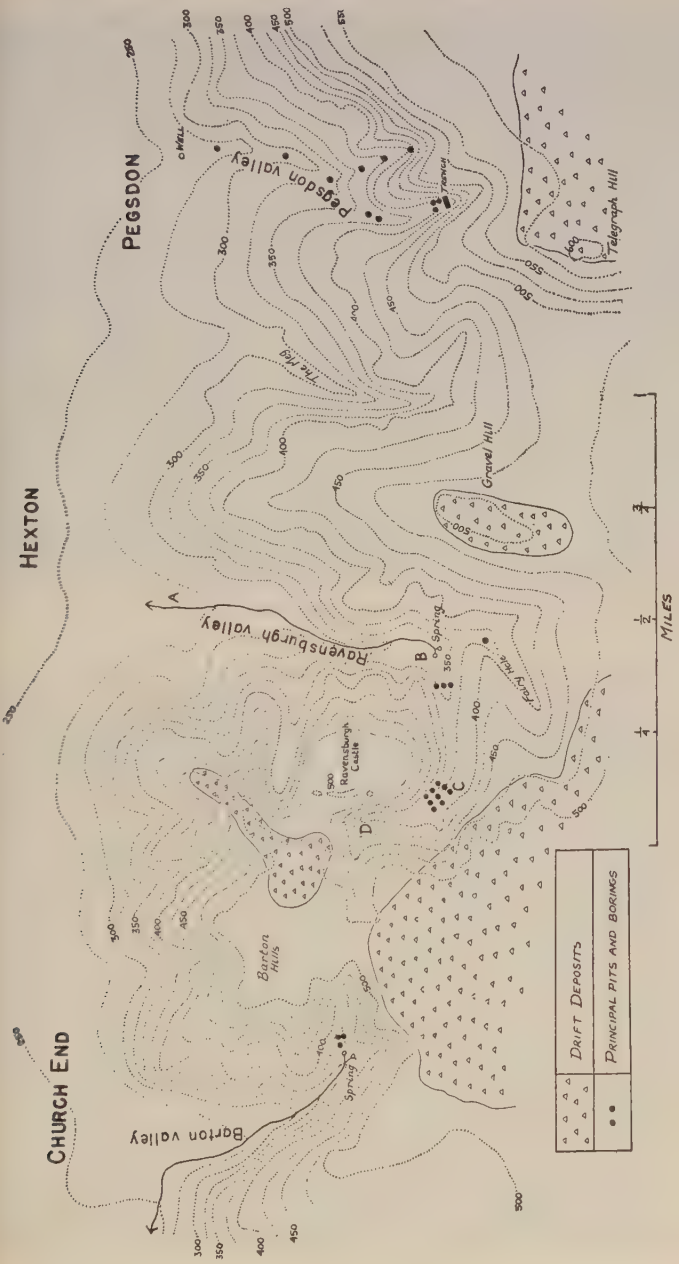


Fig. 1. Dry valleys near Pegsdon

gently undulating, while its northward-projecting spurs in places appear to preserve the remnants of erosion terraces.

The valley floors are flat especially above the springs. Thus, the Pegsdon Valley, which does not contain a spring, is flat throughout (Plate 1A), while the Ravensburgh and Barton valleys are only flat in their upper parts. The main part of the Barton Valley below the spring has a wide flat floor (Plate 1B). This, however, cut in Chalk Marl, slopes down to the stream and is genetically different from the others, as will be seen below.

The long profiles of the valleys show, with the exception of the Ravensburgh Valley, abrupt steepenings near their heads (Fig. 2). The lower parts of the profiles have slopes of three to four degrees, but there is an abrupt increase at their heads to thirteen to twenty degrees.

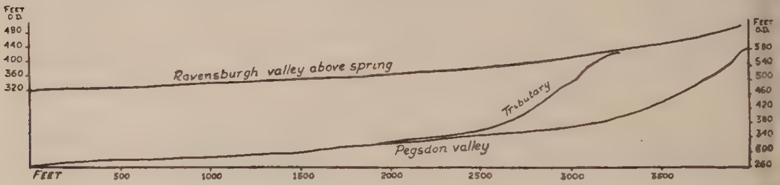


Fig. 2. Long profiles of Pegsdon and Ravensburgh valleys. (The right-hand scale refers to the Pegsdon profiles and the left-hand scale to the Ravensburgh profile)

The springs, which are thrown out at the level of the Totternhoe Stone, are small. The Ravensburgh spring is located about half-way up the valley, while the Barton spring, which does not always flow, is much nearer the head of the valley (Fig. 1). A spring occurs two hundred yards below the point where the Pegsdon Valley merges into the plain, but there is no spring within the valley. The water-level in a well at the entrance to the valley varies usually between twenty-five and thirty feet below the ground surface.

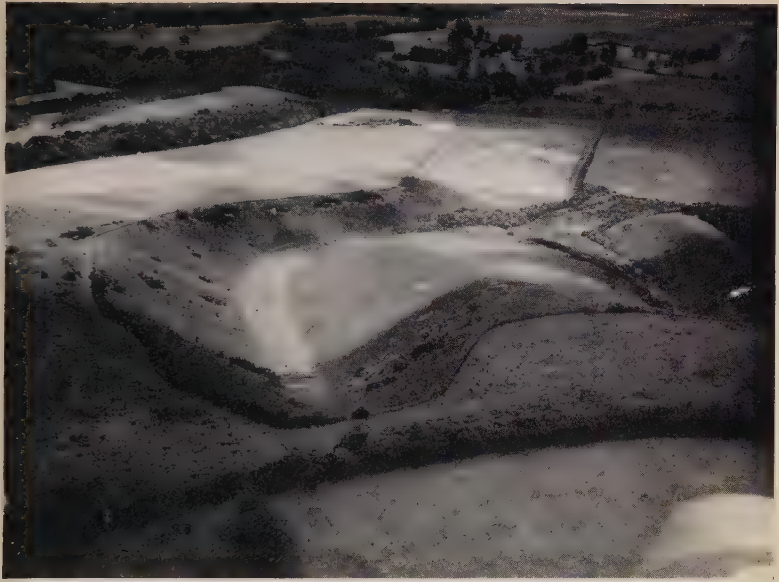
The Ravensburgh Valley is abnormal in possessing three right-angled bends. Although there are bends in the other valleys, they are neither as frequent nor as abrupt as those of the Ravensburgh Valley.

All the valleys possess tributary coombes, some of which hang above the main valleys. This feature is repeated in valleys of the same type in other chalk areas.

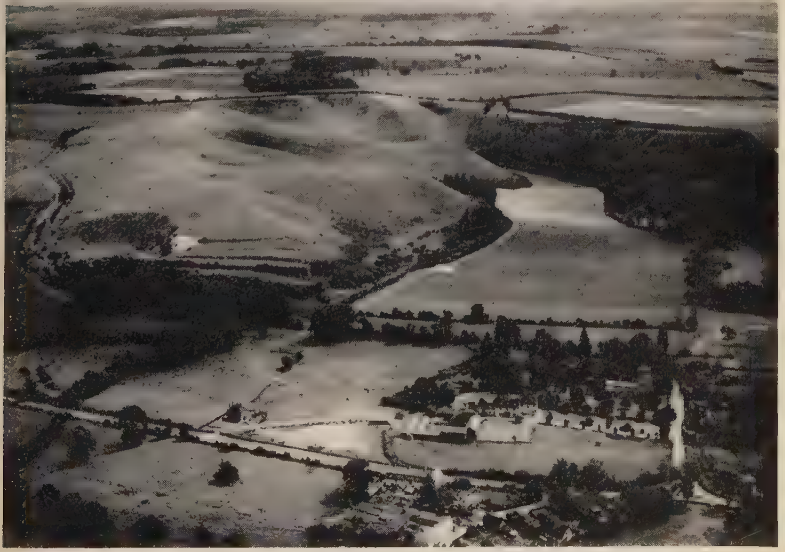
Three main problems are presented by these valleys:

1. What process or processes have formed them?
2. What is their age?
3. Why do valleys of this type have such a limited distribution?

The last is the fundamental problem and its solution may well throw light on the processes involved, but a study of the Pegsdon valleys alone



A. The Pegsdon Valley from the south: the flat floor and the upper break of slope may be clearly seen



B. The Barton Valley from the north, showing the wide floor cut in Chalk Marl

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[*To face p.* 28

cannot provide the answer. The question is at present being studied by R. J. Small of the University of Southampton.

3. THE PROBLEM OF THE MODE OF FORMATION

The problem of the processes involved may be simplified, because one apparent complication, the very flat floors, may be readily explained. An extensive programme of digging and boring in all three valleys, undertaken mainly by undergraduates of the Department of Geography, Cambridge, has shown that the very flat floors are entirely due to infill, the true cross profile being of normal type (Fig. 3). The infill consists essentially of two beds:

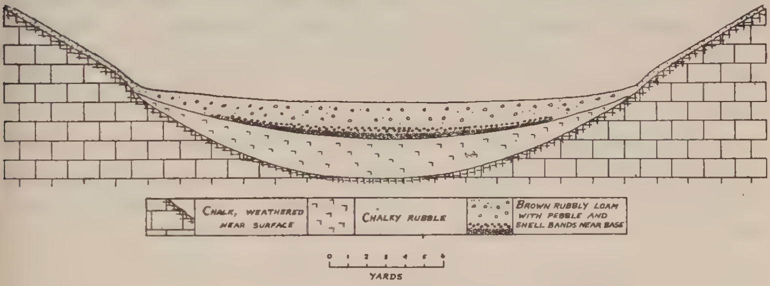
CHALK, WEATHERED NEAR SURFACE
CHALKY RUBBLE
BROWN RUBBLY LOAM WITH PEBBLE AND SHELL BANDS NEAR BASE
0 1 2 3 4 5 6
YARDS

Fig. 3. Generalised section of fill in the Pegsdon Valley

2. A light brown rubbly loam, consisting of topsoil, chalk fragments and erratics from the local glacial deposits. This varies in thickness up to about six feet, being greatest in the Ravensburgh Valley. A darker layer, with frequent mollusca, is almost invariably present at or near its base. In the upper parts of the Pegsdon Valley and its tributary there is a pebble band immediately above the shell layer. This probably represents washing in of coarser material near the valley heads, as it is not present lower down the valleys.

1. A layer of chalky rubble, usually of about the same thickness as the bed above. It consists of rounded pellets and angular fragments of chalk in a matrix of finely-divided chalk.

Beneath the chalky rubble, the surface of the chalk is weathered and the transition to solid chalk gradual.

The marked flatness of the valley floors is probably partly due to cultivation, as plough-furrows made during the 1914–18 war may still be recognised in the Pegsdon Valley. Ploughing the valley floor would tend to cut into the bottom of the waste mantle on the side-slopes, thus rendering them unstable and liable to downhill creep. Minor scars may, in fact, be seen at the foot of the slopes and in various places on the valley sides.

Centuries of cultivation may also be responsible in some degree for the sharpness of the angle between the valley sides and the summit plateaus, as this corresponds closely with the boundary between cultivated and uncultivated land (Plate 1 A). But such modifications by man by no means fully explain the youthful appearance of the valleys.

The Chiltern valleys have often been wholly or partly attributed to melt-water action (Barrow & Green, 1921; Sherlock, 1924; Kendall, *in* Earle, 1928). Usually the flat valley floors have been cited in support of this hypothesis, but the flatness is probably the result of cultivation following natural infilling. Furthermore, the deposits forming the flat floors are later than any period during which melt-water could have been present, as will be shown below. In addition, the abruptness of the valley heads cannot be reasonably explained by the melt-water hypothesis, as melt-water valleys should start gradually and become progressively incised. There seems, in fact, no evidence in favour of a melt-water origin and much against it.

Although the hypothesis of a secular lowering of the water-table, chiefly elaborated by Fagg (1923), was inspired by a need to explain dip-slope valleys, it is possible to extend it to escarpment valleys in special circumstances. If we imagine the area north of the escarpment planed off (Fig. 4), valleys such as ABC may have contained streams. After a rejuvenation, the main strike stream at C would incise itself into the Gault, thus lowering the Chalk–Gault junction and the water-table within the Chalk and causing the drying-up of the valley ABC. If this had been the operative process, we would expect traces of terraces on the escarpment and the valleys should have been dry since the last rejuvenation. Certain features on the escarpment resemble terrace remnants, so that some such process may have operated in the early stages of the formation of the Pegsdon valleys. But, as will be seen below (p. 34), there is evidence of a stream in the Pegsdon Valley in Post-Glacial times long after the last rejuvenation, so that some other cause of spring flow must be sought to explain at least the latest stages in the formation of the valleys.

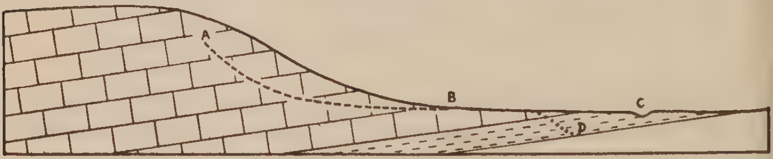

Fig. 4. Possible effects of lowering of Gault on Escarpment Dry Valley. (For explanation see text)

It has been suggested by one of us (Lewis, 1949) that the water-table within the Chalk may well have been higher in the Last Glacial period, while Arkell (1947) has attributed valleys in the Berkshire Downs escarpment to a higher water-table in the damp Atlantic phase of Post-Glacial time. In either of these wet periods the springs responsible for the valleys may well have flowed for the last time and sharpened up the form of the valleys. Some confirmation of this idea is provided by one low-level spring in the Cam Valley. Most of the springs feeding the Cam are in minute amphitheatres and provide miniature illustrations of what we think happened in the Pegsdon valleys, but the spring immediately south-west of Bassingbourn has obviously been displaced a hundred yards or so downstream from a shallow amphitheatre, which it occupied in comparatively recent times. The lowering of the water-table responsible for this is most likely to have been caused by a slight climatic change in the Post-Glacial period.

The hypothesis of spring sapping fits well with most of the known facts. It accounts for the steepness of the valley slopes and the abruptness of their heads, while the bends in the valleys are better explained than they could be by melt-water action, as was clearly recognised by Oakley (1936).

There remains the curious series of right-angled bends in the Ravensburgh Valley system, which has been attributed to sapping along major joints (Lewis, 1949), while similar bends in Steps Coombe, near Ivinghoe, led Oakley (1936) also to infer the effects of joints. Professor A. A. Miller informs us that bends in valleys in the Berkshire Downs escarpment could be similarly explained by the assumption of two sets of joints. Joint systems are not well known in the Chalk, although they sometimes control marine erosion, for example at Flamborough Head and North Foreland. But chalk is peculiar in that apparently important lithological differences appear to have little relief effect, for example the Melbourn Rock in the South Downs (Bull, 1936), while insignificant differences produce marked relief forms, as in the secondary escarpment of the South Downs (Sparks, 1949). In fact, minor structures are often only brought to light by the work of erosion, so that the assumption of joints in the Ravensburgh Valley is not completely forbidden.

One difficulty remains. Sapping can be understood in the section ABC (Fig. 1), but not so readily in the section CD, where, if the escarpment was in its present position, the water-table would have been sloping towards the escarpment, or so gently inclined towards the Ravensburgh Valley that there could have been only a very weak spring. In addition, the head of the valley is abnormal in possessing only a hint of the typical spring-head form. Fagg (1954, fig. 8) regarded this valley as the head of a former dip-slope valley captured by an escarpment valley, but the col over which it could have flowed is so high that the major work of erosion must have been performed by an escarpment stream.

4. THE VALLEY DEPOSITS AND THE PROBLEM OF AGE

A large number of pits and trenches were dug in the valley floors and further sampling done with a post hole borer. The sites of the main excavations are shown in Fig. 1. The greatest thickness of infill, seventeen feet, was found in the Ravensburgh Valley system about two hundred yards south of the spring. All the pits, trenches and boreholes showed the same general succession, described above, although the thicknesses of the two beds vary.

Material from the shell layer at the base of the upper brown rubbly loam was submitted to the late A. S. Kennard in 1946 for his comments. His list of species, with the names changed to those normally used, is given below. *Retinella radiatula* did not occur in Kennard's material, but was added after an examination of more material. In this and the following tables the actual number of each species identified is given.

Pomatias elegans (Müller)	84
Carychium tridentatum (Risso)	20
Azeca goodalli (Férussac)	2
Cochlicopa lubrica (Müller)	20
Columella edentula (Draparnaud)	1
Vertigo pygmaea (Draparnaud)	2
Pupilla muscorum (Linné)	70
Acanthinula aculeata (Müller)	7
Vallonia costata (Müller)	20
Vallonia excentrica Sterki	60
Ena montana (Draparnaud)	4
Cochlodina laminata (Montagu)	14
Clausilia bidentata (Ström)	24
Arianta arbustorum (Linné)	3
Helix nemoralis Linné	5
Hygromia ? liberta (Westerlund)	14
Helicella itala (Linné)	8
Punctum pygmaeum (Draparnaud)	2
Discus rotundatus (Müller)	28
Arion sp.	very abundant
Vitrea crystallina (Müller)	2
Retinella radiatula (Alder)	1
Retinella pura (Alder)	2
Retinella nitidula (Draparnaud)	5
Vitrina pellucida (Müller)	1
Milax sp.	12
Limax cf. *maximus* Linné	8
Limax cf. *arborum* Bouchard-Chantereaux	3
Agriolimax cf. *laevis* (Müller)	20

In his comments, Kennard stressed that the fauna probably lived in a damp scrubland with a coarse herbage, but not in woodland or in downland. It dated, he thought, from the Early Bronze Age, when many hill washes appear to have been started by man's clearance of natural vegetation. The fauna contains none of the snails, which Kennard (1923) regarded as having spread widely in Roman and later times. Approximate confirmation of this dating was provided by the discovery of a piece of pottery, which Mr. T. C. Lethbridge considered to be of Late Bronze Age or possibly Early Iron Age, at the same level, and of a piece of Romano-British grey ware at a depth of only 2 feet 6 inches in Fairy Hole, the southern tributary of the Ravensburgh Valley.

From this it is clear that the upper bed of the infill is comparatively recent and that the flat valley floors cannot possibly be due to melt-water, as they are formed of deposits of considerably later age.

At a later date snails were found in material from the lower chalky rubble at three localities: in the Pegsdon Valley (P.), in the Ravensburgh Valley (R.) and from a special boring in the main bend of the Pegsdon Valley (P.B.). The species were as follows:

	P.	R.	P.B.
Pomatias elegans (Müller)	—	—	11
Cochlicopa lubrica (Müller)	1	—	—
Pupilla muscorum (Linné)	4	—	2
Abida secale (Draparnaud)	2	—	—
Acanthinula aculeata (Müller)	—	—	1
Helix ? nemoralis Linné	—	—	frag.
Helicella caperata (Montagu)	—	1	—
Punctum pygmaeum (Draparnaud)	1	—	—
Discus rotundatus (Müller)	2	—	1
Euconulus fulvus (Müller)	1	—	—
Oxychilus cellarius (Müller)	—	—	2
Vitrina pellucida (Müller)	1	—	—
Limax sp.	1	—	—

In spite of the resemblance of the material to Coombe Rock, the fauna is as warm as that in the brown rubbly loam above, but there remained the possibility of contamination as the samples were extracted with a post hole borer. Accordingly two pits were dug in the upper part of the Pegsdon Valley, and samples taken from the upper part of the chalky rubble, from a depth of 6 feet on the east side and from a depth of 4 feet on the west. The mollusca were as follows:

	East	West
Valvata cristata Müller	1	—
Pomatias elegans (Müller)	5	3
Bithynia tentaculata (Linné)	1	—
Pupilla muscorum (Linné)	7	1
Acanthinula aculeata (Müller)	2	—
Vallonia costata (Müller)	1	—
Vallonia excentrica Sterki	1	—
Ena ? montana (Draparnaud)	1	—
Cochlodina laminata (Montagu)	1	—
Clausilia bidentata (Ström)	1	—
Cecilioides acicula (Müller)	1	—

	East	West
Arianta arbustorum (Linné)	1	—
Helix ? nemoralis Linné	frag.	frag.
Hygromia hispida (Linné)	2	—
Helicella caperata (Montagu)	2	—
Discus rotundatus (Müller)	17	—
Vitrea crystallina (Müller)	1	—
Vitrea contracta (Westerlund)	2	—
Oxychilus cellarius (Müller)	—	2
Oxychilus helveticus (Blum)	1	—
Retinella pura (Alder)	2	—
Retinella nitidula (Draparnaud)	6	—
Pisidium amnicum (Müller)	1	—

On the evidence of these shells it would appear beyond shadow of doubt that the upper part of the chalky rubble was deposited in climatic conditions at least as warm as those prevailing during the deposition of the upper loam. The possibility of the warm species having been washed down from the loam above may be discounted for several reasons. The common warm species, *Pomatias elegans*, is a large snail and unlikely to have been washed down in any numbers. Some of the warm species in the lower bed are not found in the upper: they are *Abida secale*, *Helicella caperata*, *Oxychilus cellarius* and *O. helveticus*. If any species had been washed down, it should have been *Carychium tridentatum*, a minute snail, which is not however found in the lower bed. Finally, experience of Pleistocene sections indicates that contamination of this type must be exceedingly rare, if it ever occurs.

The presence of *Valvata cristata*, *Bithynia tentaculata* and *Pisidium amnicum* establishes the probable existence of a stream in the Pegsdon Valley, for neither of the latter two species are normally found in mere surface puddles. If the dating of the base of the overlying loam as Early Bronze Age is correct, the stream would have flowed somewhat earlier, probably in the damp Atlantic period. The presence of *H. caperata* at this period is surprising, as it is normally considered to have spread later (Kennard, 1923).

There remained the possibility of a cold fauna in the lower part of the chalky rubble. From another new pit at the head of the Pegsdon Valley the following snails were recovered two feet below the surface of the chalky rubble:

Pupilla muscorum (Linné)	28
Hygromia hispida (Linné)	3
Helix ? nemoralis Linné	1
Vitrina pellucida (Müller)	2

Large samples taken from depths of three and four feet below the top of the chalky rubble yielded only isolated specimens of *Pupilla muscorum*.

Apart from the *Helix*, these snails could have withstood cold conditions, but there are so few of them that an assumption of a colder climate must be tentative. It is perhaps significant that *P. muscorum*, which often occurs in abundance in cold Pleistocene deposits, is the commonest snail here.

If the white chalky rubble was deposited under the same mild climatic conditions as prevailed during the deposition of the overlying brown loam, there remains the problem of accounting for the differences between the two beds. Perhaps the upper loam is in the main an artificial deposit formed by early cultivators scraping the thin soil into the valley both to thicken the soil and widen the valley floor, a suggestion made to us by Mr. H. H. Nicholson, Reader in Soil Science at Cambridge. Even so, we still cannot explain the differences between the two beds apparently formed under similar climatic conditions, as any chalk debris creeping down the hill-side today is thoroughly mixed with soil. The problem is a general one, because deposits of chalky material resembling Coombe Rock but containing a warm fauna, some of which have recently been described by Carreck & Kerney (1954), are known in the North Downs.

5. CONCLUSION

The valleys were most likely formed by spring sapping, and the flat floors, usually cited as evidence for melt-water action, were formed at a much later date by deposition.

The mollusca show that most of the valley infill was deposited in a warm period in Post-Glacial time, but this conclusion makes it difficult to account for the lithology of the lower part of the infill, which resembles Coombe Rock. It appears, from the presence of freshwater species, that a spring last occupied the Pegsdon Valley in a warm period in Post-Glacial time, possibly the Atlantic period. Whether the whole of the valleys were cut in that period is very doubtful in view of their size. At present the weak springs in the Barton and Ravensburgh valleys are doing little more than excavating the infill.

ACKNOWLEDGMENTS

Sir Patrick Ashley Cooper, on whose estate the valleys lie, very kindly gave us full access to the area and bore patiently with our digging. Father D. C. Britt-Compton and Dr. Marjorie Sweeting gave much assistance both in the field and in the laboratory during the early stages of the work.

REFERENCES

ARKELL, W. J. 1947. *The geology of Oxford*. Oxford.

BARROW, G. & J. F. N. GREEN. 1921. Excursion to the Tring gap and Steps Hill. *Proc. Geol. Ass., Lond.*, **32**, 215–17.

BULL, A. J. 1936. Studies in the geomorphology of the South Downs. *Ibid.*, **47**, 99–129.

CARRECK, J. N. & M. P. KERNEY. 1954. Notes on some Holocene chalk rainwashes at Cudham and Keston, near Downe, Kent. *Ibid.*, **65**, 340–4.

EARLE, K. W. 1928. Excursion to Ivinghoe and Cheddington. *Ibid.*, **39**, 492–7.

FAGG, C. C. 1923. The recession of the chalk escarpment. *Proc. Croydon nat. Hist. sci. Soc.*, **9**, 93–112.

———. 1954. The coombes and embayments of the chalk escarpment. *Ibid.*, **12**, 117–31.

KENNARD, A. S. 1923. The Holocene non-marine mollusca of England. *Proc. malac. Soc., Lond.*, **15**, 241–59.

LEWIS, W. V. 1949. The Pegsdon dry valleys. *Compass* (*Mag. Camb. Univ. Geogr. Soc.*), **1**, 53–70.

OAKLEY, K. P. 1936. Field meeting at Cheddington, Ivinghoe and Gubblecote. *Proc. Geol. Ass., Lond.*, **47**, 38–41.

SHERLOCK, R. L. 1924. Superficial deposits of S. Bucks, S. Herts, and the old course of the Thames. *Ibid.*, **35**, 1–28.

SPARKS, B. W. 1949. The denudation chronology of the dip-slope of the South Downs. *Ibid.*, **60**, 165–215.

DISCUSSION

MR. P. EVANS suggested that more emphasis might have been placed on the right-angle bends, for these are common in the scarp valleys of the Chilterns. He thought that geologists were agreed that the valley directions were controlled by the joint pattern, and near Ivinghoe there is evidence that the directions of joints and valleys closely correspond. Erosion by spring sapping would take place more readily along joints. However, the springs on the scarp slope, in contrast to those on the dip slope, are almost entirely confined to the outcrops of a few specially permeable horizons (for example, Totternhoe Stone and the Melbourn Rock) and it seems that the authors' explanation needs some supplementary hypothesis to account for springs at higher levels. The speaker referred to a suggestion by Dr. Oakley that the valleys had been initiated by the collapse of underground drainage channels, and wondered whether Dr. Bull's suggestion of erosion by melt-water from a local ice-cap might explain the cutting back of the parts of the valleys above spring level.

DR. G. H. DURY was pleased to note that the subsurface had been explored in a search for the solution to a geomorphological problem, and the authors were to be congratulated on having made a signal contribution to the study of dry valleys in the Chalk. He particularly welcomed their demonstration of a high water-table during the Atlantic phase, and their dissociation of the question of dry valleys from that of scarp retreat. It could be shown that, although many Cotswold valleys were wholly or partly dry, the Cotswold scarp had retreated hardly at all since ice last stood against it. Furthermore, the drying of some, at least, of the valleys could be placed at the very end of glacial times, if not later.

A high water-table in the Pegsdon area during Atlantic times invited comparison with events established for other areas. Jennings has shown that a large channel in the Bure Valley was swept clear during the Atlantic phase, subsequently filled with peat, and partially re-cleared during the sub-Atlantic. Thus there was evidence of high surface run-off during what were admittedly rainy periods, and at times when frozen ground could not have been present. However, the study of misfit streams indicated that high discharges also occurred at earlier times, e.g. at the extreme end of the glacial period in the valleys of the Kennet and the Dorn. The distribution of misfit streams showed that such high discharges occurred regionally; one would be therefore led to conclude that dry Chalk valleys should be explained in terms of climate rather than of the lowering of the water-table by erosion or its temporary raising by frost. He would be interested to know if investigations similar to those described had been made in valleys of the back-slope of Chalk country, or, if not, whether they are projected.

DR. K. P. OAKLEY congratulated the authors on their thorough research on a typical group of Chiltern scarp valleys, and said that he found their results readily acceptable. He had always favoured spring-sapping as the main agency determining the final form of these valleys, and he was convinced that the lines which they followed represented major joints in the Chalk. There remained the question whether some of the valleys were initially underground stream courses, and in this connection he had once ventured to suggest that the corrie-like head of Steps Coombe in the Ivinghoe area might have originated as an enlarged swallow-hole.

If further research showed that none of the scarp valleys was filled by Pleistocene Coombe Rock, the question would arise whether the scarp line had retreated considerably since the Last Glaciation. The great mass of Coombe Rock at the foot of the escarpment exposed in the Tunnel Cement Company's works at Pitstone was certainly of Pleistocene age, for frost-polygons had been detected in its upper layers (*Proc. Geol. Ass., Lond.*, **63**, 61); and so presumably was the gravelly Coombe Rock in the dry valleys which trenched the dip-slope. Similar gravel on the floor of the Wendover gap contained remains of mammoth.

PROFESSOR A. A. MILLER said that many of the features noted are matched in similar valleys on the scarp face of the Berkshire Downs at Bishopstone near Swindon, where excavations had been carried out by geography students from Reading University. These lie beyond the limits of the ice-sheets and true glacial drifts, though peri-glacial conditions must have obtained there at times. About sixteen feet of Coombe Rock were dug and bored through in the infill of the largest of these valleys but no shell bands were found.

In trenches dug through the system of strip-lynchets on the valley sides the subsoil surface of Lower Chalk had been laid bare showing hard blocky bands intercalated with soft chalk. Despite their superior mechanical hardness the blocky layers had no noticeable effect on relief and did not make shelves along the scarp face. This supports the suggestion made by Mr. Sparks that the shelves usually attributed to the Totternhoe Stone in Cambridgeshire are more likely erosional features preserved by the accident of local coincidence with the outcrop.

Joints were noticeable and wide on the exposed surfaces of the hard bands at Bishopstone, but their direction was too irregular to warrant confidence in correlating the zig-zag valleys with joint direction.

He drew attention to the scalloped form of the Berkshire Downs escarpment in plan and to the radially centripetal pattern of the dip-slope drainage focusing fanwise on Lambourn and Aldbourne and suggested that both form of scarp and pattern of drainage might be symptoms of minor flexures (pitching synclines). The three valleys described in the paper (Barton, Ravensburgh and Pegsdon) are radially divergent on a projecting curve of the escarpment and similarly might betray a cryptic joint pattern related to the stresses of minor folding.

In reply, MR. W. V. LEWIS, on behalf of the authors, said that Mr. Evans's reference to the influence of jointing on valley direction had his strong support. The evenly distributed rainfall that percolates into the Chalk, discharges from the scarp foot in well-defined springs about a mile apart. This marked concentration of underground water movement in specific channels leading to the springs, points to the very real influence of major joints. If, then, spring recession does occur it would seem natural for it to follow the water conduits formed along these joints. Mr. Evans also rightly drew attention to the influence of horizons such as the Totternhoe Stone and the Melbourn Rock in locating these scarp foot springs. But the water-table is very mobile even under present supposedly equable climatic conditions, rising and falling fully 150 feet at Chilgrove and Compton on the dip slope of the South Downs.[1] This is fundamentally due to evaporation losses varying less than the rainfall, and thus leaving a very variable quantity of water for seasonal percolation. Data kindly supplied by Mr. P. Porteous, Engineer to the Cambridge University and Town Waterworks Company, illustrate this point. Between 1937 and 1956 rainfall at Cambridge varied between 14.9 and 28.1 inches, whereas percolation through the turfed gauge varied between 2.7 and 13.6 inches, the corresponding evaporation and transpiration losses varying only

[1] In the discussion I wrongly referred to the flooding of Lord Kennet's house in a Wiltshire dry valley in the winter of 1939–40 as due to the rise of the water-table. Mr. Evans kindly reminded me after the meeting that it was due to frozen subsoil (see *Proc. Geol. Ass., Lond.*, **53**, 139).

between 11.8 and 17.6 inches. These variable supplies of percolation cause marked fluctuations of water-level even near scarp foot springs. During the floods of 1947 the water-level in the well at the mouth of the Pegsdon Valley, which normally fluctuates between depths of twenty-five and thirty feet, rose to within ten feet of the top of the well in spite of the spring being only 200 yards away. Assuming that such peaks were higher and more frequent and prolonged during some periods of post-glacial time, may not the springs have eaten back slightly uphill into the escarpment during these intermittent high levels? In doing so the springs would gradually rise above the horizon of the Totternhoe Stone, the regional dip of which is in the opposite direction to that of the water flow, although this bed may continue to control the level of the lower, more permanent springs.

Dr. Oakley, with whose work we very much agree, poses the problem of the enlargement of the heads of the Ivinghoe coombes. May this not result, at least in part, from the subdivision of springs as occurs in the Barton-in-the-Clay Valley? Headward recession may be greatly retarded at such points, and thus increase the chances of such a stage being preserved if the water-table subsequently falls. The modification of such valley heads by occasional surface run-off over frozen ground must also be considered. Such modification has certainly occurred with the Pegsdon valleys.

Dr. Dury's evidence of the enlargement of valleys during periods of heavy rainfall is interesting. We have not done detailed work on the dip-slope valleys but have purposely concentrated on a particular type of scarp face valley which seems to demonstrate the spring-sapping hypothesis.

MR. B. W. SPARKS, in reply, considered that the apparent absence of true Coombe Rock from the immediate foot of the escarpment and its valleys was probably a local feature due to later erosion. One could not safely assume that there had been a great amount of escarpment recession here in very recent times, for most of the evidence from along the escarpment, for example the fragments of erosion terraces on the escarpment near Pegsdon, suggested that it had remained stable for a long period.

He agreed with Professor Miller that the Pegsdon valleys, like those of the Berkshire Downs, were cut in a projecting part of the escarpment, but thought that in other areas the same relationship was not always found.

No investigations had been made into the deposits of dip-slope valleys, but news of promising sections or material would always be welcome.

Borehole Records from the Lea Valley in the Neighbourhood of Edmonton, Middlesex

by JOHN F. HAYWARD

Received 27 November 1955

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ABSTRACT: Three lines of boreholes in the Edmonton and Southgate district give fresh evidence of the minor tectonic structures to which the Eocene rocks have been subjected.

A deposit resembling till is found to underlie the gravels of the Hedge Lane channel.

1. INTRODUCTION

IN A previous paper (Hayward, 1955) a description was published of a series of boreholes between Cheshunt and Edmonton. These revealed that the Eocene beds were thrown into an anticline with its axis through Brimsdown. The present work describes some twenty-seven boreholes carried out more recently which lie in three lines as follows:

A. A series of eleven which continue in a southerly direction the line described in the previous paper.

B. Eight boreholes along the Great Cambridge Road between Salmon's Brook, Lower Edmonton and Lordship Lane, Tottenham.

C. A further eight stretching across the lines of the other two from Deephams Sewage Works, Edmonton, along the North Circular Road as far as Colney Hatch Mental Hospital.

A map of the area is given in Fig. 1, and sections along the three lines are to be found in Figs. 2 and 3.

2. THE BOREHOLE RECORDS

Section A. The line of boreholes continues for two and a half miles southwards beyond the series already described. In the previous section an anticline was observed near Brimsdown and part of the complementary syncline was proved. A second anticline is now found with its axis close to Angel Road Station, Edmonton. Thus, the distance between the axes of the two anticlines is approximately two and a half miles when measured

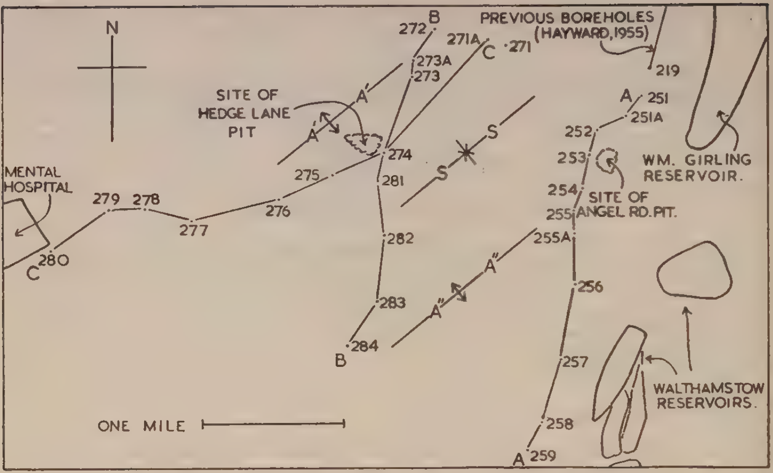
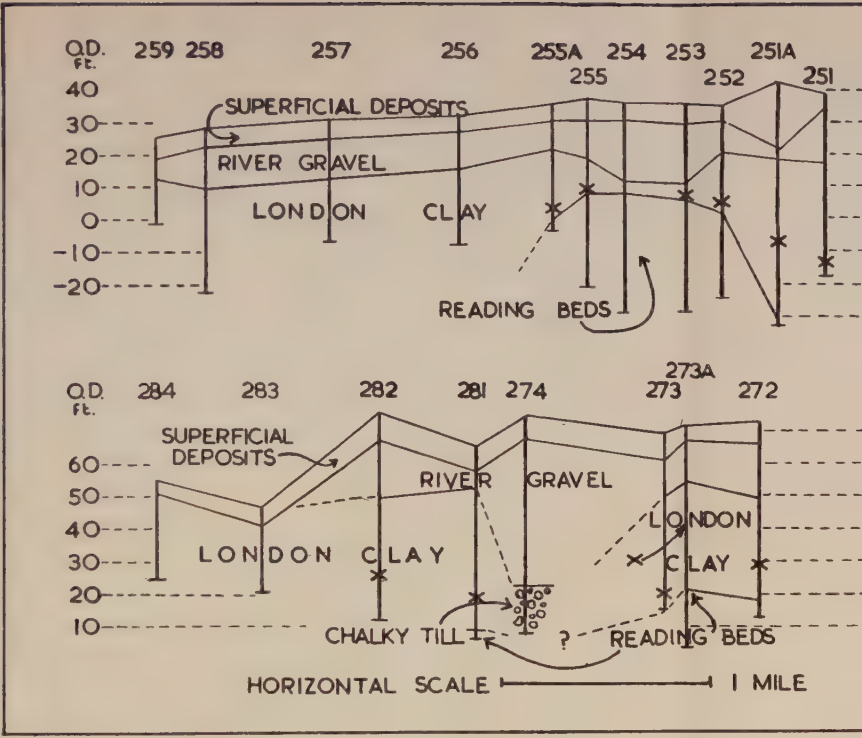


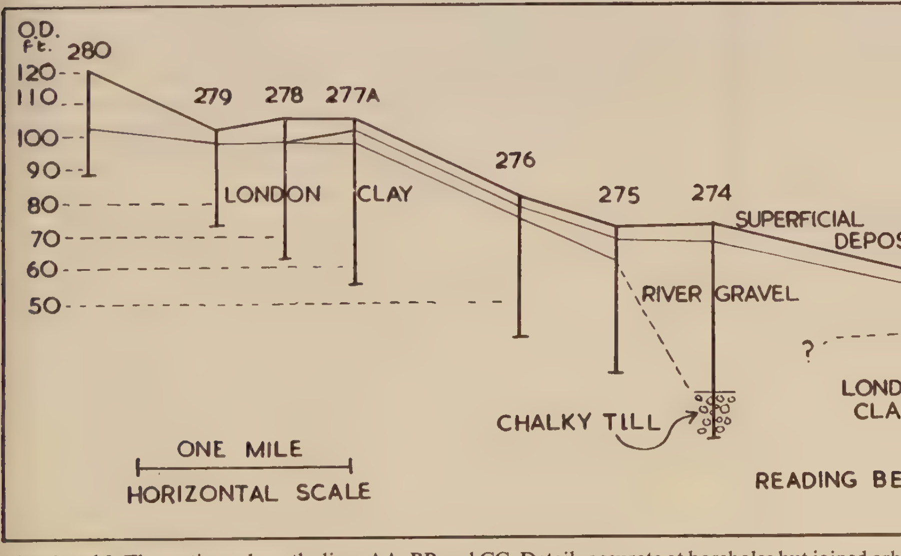
Fig. 1. Sketch map of the area showing the position of the boreholes:
AA, BB, CC. The lines along which the sections in Figures 2 and 3 are drawn.
A′. The approximate direction and position of the more northerly anticline, obtained by joining the highest points of the fold in two sections.
A″. The approximate position of the more southerly anticline, proved in one section only and drawn parallel to A′.
S. The approximate position of the intermediate syncline, interpolated between A′ and A″. This syncline forms the long axis of Epping Forest and passes through Hampstead Heath

along the line of the section. The highest point attained by the Reading Beds in the more southerly fold is eight feet O.D., that is about twenty-four feet lower than the other, and the fold seems less asymmetrical than the previous one.

The Reading Beds appear to fall almost entirely within the uppermost of the three subdivisions quoted in the earlier paper and consist chiefly of pale silty clays below and red and grey mottled clays above. The following, in borehole 253, gives the best section of the Reading Beds in the series:

	ft.	in.		ft.	in.
Superficial deposits				26	0
London Clay				5	0
Grey and red mottled clay ...	6	6	Reading Beds seen to	34	0
Pale grey silty clay becoming paler with depth	10	6			
Grey and red mottled clay ...		6			
Grey silt	1	6			
Grey and red mottled clay ...		6			
Dark grey unconsolidated silt with some pebbles (some parts a little more compact) ... seen to	14	6			





Figs. 2 and 3. The sections along the lines AA, BB and CC. Details accurate at boreholes but joined arb
Doubtful details indicated by dotted lines.
X indicates the approximate position of a sandy, often glauconitic horizon in the London Clay.

Although the two divisions of the London Clay quoted in the previous paper were not exactly observable there was a tendency for grey fissile clay to predominate in the upper part and for grey-brown silty clay to be found in the lower part. In several boreholes a horizon of fine water-bearing silt, sometimes glauconitic and sometimes bearing shell fragments, was observed. These levels, which are marked with an 'X' in the text figures, presumably represent the lenses of glauconitic sand already recorded.

In very few cases did the surface of the London Clay take on a fawn-grey colour. Generally the surface was grey-blue and unweathered, a fact which agrees with the data already published. It will be seen that this does not always apply in the boreholes which are farther up the sides of the valley.

The superficial deposits, of gravel followed by marsh clay and made ground, roughly follow the surface contours except near boreholes 253 and 254 which presumably lie within the area of the Angel Road channel (Warren, 1912).

Section B. This series makes a line roughly parallel to the first at rather more than a mile to the west. Its significance is that one borehole is close to the classic Hedge Lane pit of Warren (1916).

The Reading Beds are found in boreholes 272 and 273a and again in 281. In the first and last of these only the top is seen but in the other the typical grey and red mottled clays lie on a series which include a type of 'chalky' clay and a bed of hard 'limestone'. Although this latter gave a positive reaction with acid, examination proved that it was a sandstone cemented by a certain amount of calcium carbonate. The same bed appears in borehole 271a and will be further discussed below. The fold which brings up these beds is assumed to be a continuation of that shown in the previous paper. This is in accordance with existing views which stipulate a synclinal fold which passes through Epping Forest and Hampstead Heath, with complementary anticlines to the north and south (Wooldridge, 1922).

The sequence in borehole 273a is as follows:

	ft.	in.		ft.	in.
Superficial deposits				17	6
London Clay				33	0
Grey and red mottled clay	3	6	Reading Beds seen to	18	6
Dark grey clay	2	0			
Grey and red mottled clay becoming darker with depth	6	6			
Soft grey sandy clay	1	0			
White 'chalky' clay with fragments of soft 'limestone'		6			
Sand cemented with calcium carbonate ('limestone')	1	0			
Pale grey silty clay with fragments of soft 'limestone' ... seen to	4	0			

The London Clay in this section presents no new features. In borehole 273a the mottled clay of the Reading Beds is followed by one foot of pale grey silty clay with Eocene-type pebbles, and this is taken to be the Basement Bed. In 281 the base is represented by one foot of 'claystone' which is not, however, typical of the concretions, whether septarian or not, to which this name is usually given. The samples examined contained abundant black flakes of organic matter which may be plant or arthropod remains but are not easily identifiable. A marked bedding plane is seen in one sample. This rock may represent the consolidated facies of the Basement Bed which is found in a number of localities in the London Basin.

In borehole 284 the surface of the London Clay has been weathered brown to a depth of fifteen feet and samples exhibit partly decomposed nodules of pyrite and sphaerulites of selenite, one of which was an inch across.

Borehole 274, on the east side of the Great Cambridge Road, is either within or very close to the eastern part of the former Hedge Lane pit in the area of which Warren wrote: 'Subsequent working towards the east has shown that the plant bed sinks deeper and increases to ten feet in thickness. Its removal has become so expensive and unprofitable that the deeper working has been abandoned' (1916).

The borehole log records forty-six and a half feet mainly of brown sandy gravel but with here and there a bed of brown clay. Unfortunately the bore did not reach the underlying Eocene beds, but the lowest part of the section consisted of twelve and a half feet of a firm grey or grey-brown sandy clay with some pebbles and fragments of chalk. Three samples of this were obtained at five-foot intervals and they differed mainly in the amount of chalk present. Two of them contained fragments of thick oyster shells which appear to be of Jurassic or Cretaceous types, forms which are commonly found in local glacial deposits. It is difficult to escape from the conclusion that the bottom of the Hedge Lane channel is lined with till. If this is taken to mean that the channel was eroded before the time of the Chalky Boulder Clay, perhaps as early as the Great Interglacial, this would indicate an abnormally deep downcutting. An alternative theory that a frozen mass of Boulder Clay was dropped into the valley during the Ponders End Stage is not without attendant difficulties. A reasonable explanation might be that echoed by several authors, namely that the Hedge Lane channel is of Taplow Terrace age. If this hypothesis is accepted, the till will represent a mass of Chalky Boulder Clay which was dropped into the valley during what corresponds to the Main Coombe Rock Solifluxion Stage of the Thames Valley.

In his paper of 1916 Warren assumed that the Hedge Lane channel was cut into the London Clay. An examination of the data suggests that in this area the Reading Beds are at a high level and it may be that the channel deposits rest directly on these. In fact during the boring operations no water was encountered and any water which the contractors poured into the borehole rapidly disappeared. It is therefore not beyond the bounds of possibility that the channel has actually cut out the uppermost Mottled Clays and that its lowest point is in the silty beds below. Mr. Warren, in conversation with the author, has recalled that this pit was inexplicably dry.

Section C. This line of boreholes stretches for about three miles in a direction approximately at right angles to the other two, crossing the second series at borehole 274. It therefore traverses the channel just described and climbs up the side of the valley on to the level of the fifty-foot terrace.

Reading Beds are seen at the very bottom of borehole 271a and it may be assumed from the evidence seen in other sections that these beds rise again in the neighbourhood of boreholes 276 and 277a. These were not, however, sunk deeply enough to reach the Reading Beds. The 'limestone' recorded in borehole 273a was encountered again between five and seven feet O.D. in 271a. Again it was found to be a sand which had been cemented by calcium carbonate, the latter taking on a mammillary form on the outside of some blocks. No doubt the calcium carbonate had been carried down in solution from the chalky till already discussed.

Most of the boreholes in sections B and C exhibited a weathering, sometimes to a considerable depth, of the uppermost part of the London Clay. In this the clay on the sides of the valley differs from that beneath the flood plain.

ACKNOWLEDGMENTS

Again the author acknowledges permission granted on behalf of the Middlesex County Council to examine borehole logs and samples, to be present on occasion at the boring operations, and to publish this report. He acknowledges the kind co-operation of the Consulting Engineers, Messrs. J. D. and D. M. Watson, M.M.I.C.E., and their resident engineers, and various geologists who are always pleased to discuss such results with the author. Mr. P. C. Lodge gave valuable photographic assistance.

APPENDIX

BOREHOLE DETAILS

Borehole No.	National Grid Reference	Level of Surface O.D.	Depth ft.
251	51/355934	38.4	56
251a	354932	42.5	75
252	350930	35.5	60
253	350927	36.3	65
254	349923	36.2	65
255	348921	36.3	57
255a	348919	35.6	40
256	348913	31.8	40
257	346904	30.3	37
258	344897	28.4	50
259	342894	25.4	27
271	340940	51.6	42
271a	339941	53.1	56
272	332942	71.8	59
273a	330938	72.1	69
273	330937	69.4	55
274	326928	73.7	65
275	321925	72.3	44
276	315923	81.5	42
277 Not Bored			
277a	305921	105.0	49
278	300922	106.0	43
279	295922	102.1	29
280	288917	120.5	32
281	325925	63.8	58
282	327918	76.0	64
283	325911	46.7	26
284	322905	55.2	30

REFERENCES

HAYWARD, J. F. 1955. Borehole Records from the Lea Valley between Cheshunt and Edmonton. *Proc. Geol. Ass., Lond.*, **66**, 68.

WARREN, S. H. 1912. A late glacial stage in the Lea Valley. *Quart. J. geol. Soc. Lond.*, **68**, 213.

———. 1916. The late glacial stage of the Lea Valley. *Quart. J. geol. Soc. Lond.* **71**, 164.

WOOLDRIDGE, S. W. 1922. The minor structures of the London Basin. *Proc. Geol. Ass. Lond.*, **34**, 175.

Pyrite Nodules in the Hythe Beds of the Tilburstow Hill Area, Surrey

by WILLIAM E. SMITH

Received 6 October 1955

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ABSTRACT: Pyrite nodules from the Middle Hythe Sands of the Tilburstow Hill area of Surrey are described, apparently for the first time. The limonitic crusts of the nodules contain shattered quartz grains and have a higher cement:grain ratio than that of the unaltered cores. It is suggested that these phenomena are the result of the alteration of pyrite. A mechanism for the formation of hollow ferruginous concretions (boxstones) is also suggested.

1. INTRODUCTION

PYRITE is widely distributed in shales and limestones but is much less common in sands and sandstones. This is no doubt due to the ease with which pyrite is altered by oxygenated meteoric waters which circulate in sands more readily than in other rock-types. The author was therefore surprised to find that pyritic nodules are common in the unconsolidated Hythe Sands in the Tilburstow Hill area of Surrey. References have been made to 'ironstone' in these sands (e.g. Bull & Gossling, 1948) but no indication has been given that some of the nodular masses are not typical carstone inasmuch as they have pyritic cores. X-ray crystallographic analysis confirmed that the cement in these cores is predominantly pyrite and not the orthorhombic iron disulphide, marcasite.

The nodules described in this paper were all collected in the large sand-pit by the side of the road leading to Underhills, south of the Tilburstow Hill–Bletchingley road. A few altered nodules were found in the sands exposed to the east of Tilburstow Hill but they appear to be very local in distribution.

2. THE OCCURRENCE OF THE NODULES

The Underhills section is rapidly deteriorating by sand-slipping and the spread of gorse-bushes. Nevertheless it still shows a near strike-section exposing about seventy feet of sands. These sands are capped by thin beds of sandstone and, at the eastern end of the pit, by thick masses of chert. The majority of the nodules were found loose on the floor of the pit. After a careful search, however, they were located *in situ*, in calcareous glauconitic sands containing scarce silicified fossils such as *Exogyra sinuata* (J. Sow.). These sands agree closely with the description by Bull & Gossling (1948) of the Middle Hythe Sands of the Tilburstow Hill area. As far as could be ascertained the nodules occur sporadically in these sands but are most common at certain levels.

3. DESCRIPTION OF THE NODULES

The nodules are usually spherical or ellipsoidal, with diameters ranging from two to five centimetres (Plate 2). A few larger ellipsoidal masses with long axes up to twenty centimetres and some highly irregular nodules have also been observed. In most cases the surfaces of the nodules are comparatively smooth with only minor rounded protuberances but occasionally show numerous sharp projections such as are formed by radial crystal-growth. Internal cracks extending to the surface of the nodule are not uncommon and in some cases are filled with white fibrous selenite.

When broken the nodules always show a firmly cemented deep-brown limonitic crust, usually about five millimetres thick (Plate 2E). Although the cores of the nodules vary considerably in nature and appearance they are always quite distinct from the limonitic crusts. In some cases the cores are hard and greyish, the metallic lustre of pyrite being readily seen, especially under a hand-lens. It is then apparent that granular pyrite functions as the cement for numerous sand-grains. In most cases, however, the cores consist of rather incoherent material, greenish-grey in colour and only occasionally showing the glint of pyrite. This appears to represent early stages in the alteration of the pyritic cement since other nodules, whilst retaining all the external features of those possessing pyritic cores, are incompletely filled with red, yellow or brown sand and undoubtedly represent completely altered examples (Plate 2C). Chemical examination of the greenish-grey material found in partly altered nodules shows that it is still rich in fresh pyrite. The grains of pyrite in the cement have lost their original cohesion as a result of the superficial formation of alteration-products.

In thin sections the pyritic cement is completely opaque. The enclosed sand-grains are comparatively well graded, subangular in shape and consist almost entirely of quartz with a few grains of fresh green glauconite.

There appears to be no doubt that the nodules were produced by the localised cementation of the Hythe Sands. Nevertheless, while most of the grains have retained their water-worn boundaries, a few of the grains of quartz have embayed or slightly crenulate outlines, suggesting that some marginal replacement by pyrite may have occurred. The junction between the crust and core is not so sharp as the macroscopic appearance suggests, thin stringers of limonite penetrating for a varying distance towards the centre of the nodule. The limonite in the crusts not only functions as the cement for sand-grains but also occurs as distinct veins cutting across both matrix and grains (Plate 3 C). These veins are particularly frequent in the outer part of the crusts and sometimes divide grains into several segments. In some cases these limonitic veins are continuous with selenitic veins which cut across the core of a nodule. In no case, however, does the pyrite occur as veins traversing sand-grains. The cracks indicated by the limonitic veins were therefore not a primary feature associated with the growth of the pyritic cement. Their infilling by minerals which would be produced during the oxidation of pyrite suggests that they are a secondary feature, i.e. formed at some stage during the alteration of the nodules.

In polished sections the cement of the unaltered parts of the nodules can be seen to consist of variously shaped grains of pyrite which interlock with the sand-grains (Plate 3 A). A few irregular grains of marcasite, conspicuous under crossed nicols by virtue of their birefringence and twin lamellae, and a little interstitial fine-grained calcite and selenite are also present. Polished sections of the limonitic crusts show that their cement consists of cryptocrystalline goethite and haematite (? turgite) (Plate 3 B). The two oxides are intergrown in places and also occur as alternate irregular zones roughly parallel to the surface of the nodules. The secondary limonitic veins cutting across both the matrix and sand-grains in the crust are composed of goethite.

4. THE ALTERATION OF THE NODULES

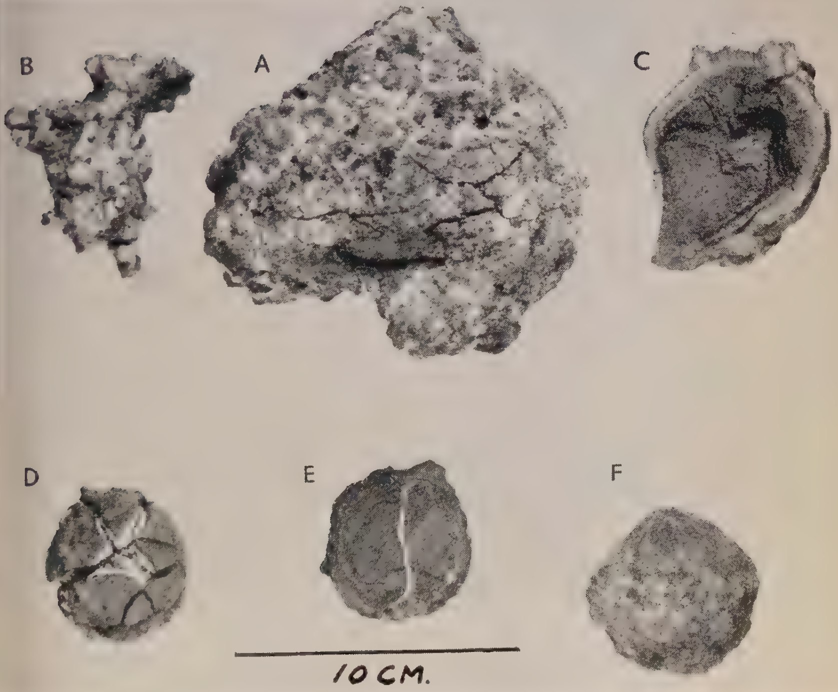
There seems to be little doubt that the limonitic crusts of the nodules were produced by alteration of the outer parts of once completely pyritic nodules, although peripheral accretion of limonite may have occurred in some cases. The irregular junction between the pyritic and limonitic parts of the nodules is most easily explained by presuming such surface alteration. The most convincing evidence comes from the occasional nodule, the exterior of which resembles those of undoubted limonite pseudomorphs after radial aggregates of pyrite. Furthermore, the selenite veins clearly indicate that even in the freshest nodules some oxidation of pyrite has taken place.

Microscopic examination of thin sections of the limonitic crusts of the nodules provides convincing evidence that considerable pressures developed during their growth. In most cases the cement:grain ratio is distinctly greater in the crusts than in the cores (Plate 2B). This suggests that sand-grains in the crusts have been forced apart. More surprisingly, as stated above, some of the quartz-grains have been shattered, limonitic veins passing completely through them. Indeed some grains are split into several segments by the penetration of many such veins. The relationship between the limonite and quartz-grains is very complex. In some cases there is clear evidence of the physical penetration of limonite into the grains. For example, small triangular grain-fragments between intersecting veins of limonite are sometimes appreciably displaced. Furthermore, some of the shorter veins cutting only part of a grain narrow inwards, as if cracks had been forced apart by material being pushed into them. Thin transparent limonitic veins are also present in many of the grains and appear to represent hair-cracks possessing limonite-coated surfaces.

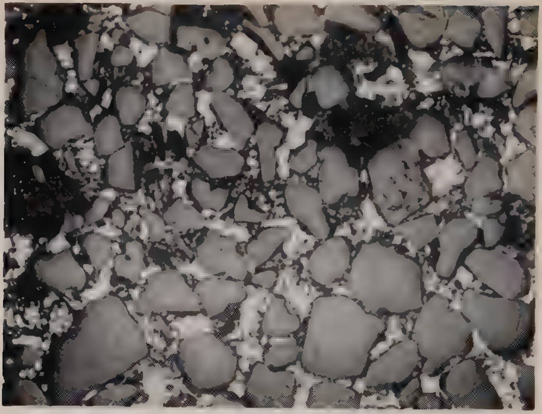
In other cases parallel veins of limonite cutting right across quartz-grains are so numerous that they are separated by only thin slivers of quartz (Plate 3C). These thin slivers are in optical continuity with each other and with the parent grain. One might have expected that such small fragments of quartz would be disturbed by any penetration of limonite into cracks in the parent grain. Chemical replacement of quartz by limonite along pre-existing cracks would therefore seem to be a more plausible explanation. Nevertheless secondary veins of limonite, which undoubtedly fill cracks in the crust, split locally into several sub-parallel branches which divide grains into small segments. Notwithstanding the difficulty in accounting for the apparent lack of disturbance of these small grain-fragments, the author considers that the physical penetration of limonite into cracks in the grains was responsible for most, if not all, of the observed phenomena. Nevertheless the question of replacement must remain open. The parallelism of many of the veins is probably due to the presence of original planes of weakness in the quartz-grains such as are indicated by lines of inclusions in some of the grains.

When left standing in the laboratory the pyritic nodules have a strong tendency to shed their limonitic crusts. At the same time the crusts develop numerous irregular cracks, some of which penetrate into the interior of the nodule (Plate 2D). This behaviour is due to the growth of a white acid encrustation rich in hydrated ferrous sulphate (melanterite), which forms beneath the crust and by continued growth is capable of pushing away the crust. This melanteritic encrustation appears to be quite stable since, apart from further growth, no other changes have been observed in nodules kept for several months. When the encrustation is moistened with water, however, and finely divided calcium carbonate added, a brown ferric hydroxide scum forms in a matter of minutes. This suggests that further oxidation and hydrolysis of the melanterite rapidly follows neutralisation of the free sulphuric acid contained in the encrustation. That such

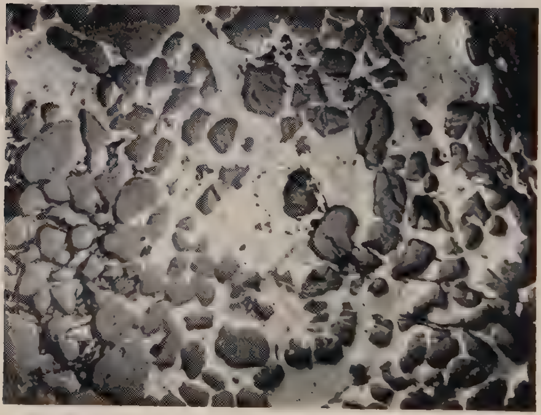
PLATE 2



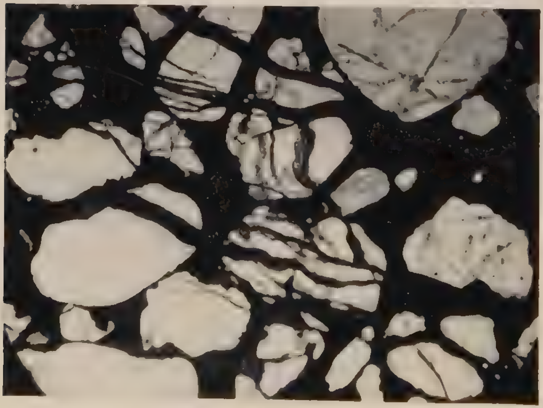
A



B



C



neutralisation occurred during the alteration of the pyrite nodules in the field is indicated by the fact that they often contain veins of selenite.

The behaviour of the pyrite nodules left standing in the laboratory shows that the formation of melanterite during the oxidation of pyrite is accompanied by an increase in volume. Calculation of the molecular volumes of pyrite, melanterite and limonite, taking the latter as cryptocrystalline goethite shows that (a) the transformation pyrite→melanterite should be accompanied by a large increase in volume (146:24), while (b) any increase in volume accompanying the transformation pyrite→limonite is probably very small. The latter conclusion is supported by the undistorted nature of limonite pseudomorphs after pyritised fossils or cubes of pyrite.

The author considers that the pushing-aside and fracturing of quartz-grains in the crusts of the nodules under consideration was due to the formation of melanterite during the weathering of the nodules. The only other source of pressure which could have produced the observed phenomena is the force of crystallisation exerted by limonite. That the force of crystallisation exerted by pyrite was not responsible is shown by the complete absence of pyrite-filled cracks and by the contrast between the cement-grain ratio of the cores and crusts. Fractured sand-grains traversed by limonitic veins can sometimes be seen in iron-pan or carstone which presumably have never been pyritic (e.g. Hallimond, 1925, fig. 32, p. 132). In such cases one is forced to invoke the force of crystallisation exerted by growing limonitic aggregates as responsible for the fracturing of the sand-grains.

In the case of the limonitic crusts of the pyritic nodules, however, any such force is considered to have been supplemented by that associated with the growth of melanterite, because:

(a). The crusts do not appear to have been formed by the peripheral accretion of limonite derived from an external source. The limonite in the crusts was derived from the outer part of the pyritic cement of unaltered nodules. Since there is little or no volume-change associated with the transformation pyrite→limonite it is difficult to see how the formation of simple limonite pseudomorphs after the pyritic cement could have given rise to pressures capable of fracturing occluded quartz-grains. On the other hand, the volume-change associated with the transformation pyrite→melanterite provides a source of pressure which is capable of cracking the hard limonitic crusts of the nodules.

(b). The veins of limonite and selenite which penetrate deeply into the nodules were deposited in cracks analogous to those produced in cases where the formation of melanterite has actually been observed. The growth of melanterite beneath an earlier-formed crust provides a mechanism explaining the limonite-filled cracks which penetrate both matrix and grains in the outer part of the nodules.

(c). The veins of selenite traversing the cores of some of the nodules suggest that the alteration of pyrite has taken place beneath the crusts. In such cases the restricted supplies of oxygen and water within the nodules would favour the formation of melanterite rather than the more highly oxidised and hydrolysed substance, limonite.

5. CARSTONE VEINS

After the early stages in the alteration of a pyrite nodule it would become increasingly difficult for the oxidation of pyrite to continue beneath the crust. Alteration of the nodule would eventually come to an end provided the crust remained uncracked. When cracks developed in the crusts, however, alteration could continue and might lead to further cracking. In such cases any melanterite which formed beneath the crusts could only undergo further oxidation and hydrolysis within the cracks or in the sands surrounding the nodules. The plugging of cracks by limonite could occur at almost any stage in the alteration of a nodule, a fact which accounts for the wide variation in the state of the cores.

The process outlined above also explains the approximate constancy in the thickness of the crusts. These are always about five millimetres thick even in completely altered nodules. Despite the complete cementation of unaltered nodules no completely cemented limonite pseudomorph has been found. Completely altered nodules have a firmly cemented crust but are always filled with loose iron-stained sand. This suggests that after the formation of a certain thickness of crust iron compounds migrated away from the original cement of the interior.

Irregular veins of carstone are common in the Middle Hythe Sands in the Underhills sand-pit and in many small exposures further east. The glauconite in these sands is comparatively fresh and was clearly not an important source of the limonitic cement in the carstone veins. On the other hand, the limonite in these veins could have been produced by the oxidation and hydrolysis of ferrous salts which diffused into the ground-waters during the weathering of the pyrite nodules. The diffusion of iron salts from local centres is suggested by rings or ovals of loosely cemented ferruginous sand which are well developed in the western part of the Underhills sand-pit. These rings are a foot or more in diameter but their incoherent nature makes it difficult to determine their exact three-dimensional form. They appear to be sections of hollow spheres or ellipsoids of iron-stained sand. No trace of pyrite has been found within the sand enclosed within the rings. Nevertheless their shape and the fact that they occur at the pyritic horizon suggest that they were formed by the deposition of limonite from iron salts diffusing from pyrite nodules during their alteration.

6. HOLLOW FERRUGINOUS CONCRETIONS

L. L. Smith (1948) has suggested that hollow ferruginous concretions in Mesozoic and Cainozoic sands in South Carolina result from the deposition of limonite in excess of that required to fill the interstices between sand-grains. He considers that the deposition of limonite first begins about certain favoured centres and proceeds outwards from the initial region of deposition. 'After [the] interstitial spaces are filled, additional deposition of limonite forcefully wedges the sand-grains apart. The crustal area expands, whereas the core receives little or no secretion after completion of interstitial filling, with the result that the growing concretion develops a hollow interior' (p. 220). He cites increases in the cement: grain ratio, the shattering of quartz-grains and the bending of mica-flakes as proof of the expansion of the crusts. Apart from the bending of mica-flakes, these phenomena can be observed in hollow ferruginous concretions in the Hythe Sands, nevertheless L. L. Smith's theory is not applicable to them. These hollow concretions contain loose iron-stained sand but were not formed by the diffusion of iron salts *towards* a growing crust. There seems to be no doubt that they were produced by the diffusion of iron salts *away* from a pyritic centre. The loose sand within the limonitic shells has not been left behind by the growing shells but has merely lost its original pyritic cement. Some of the limonite formed from this pyritic cement has gone into the shells where it has filled spaces created by the displacement and fracture of sand-grains. The rest, apart from that left as a superficial stain on the sand-grains within the shells, has presumably contributed to the formation of the carstone veins in the Middle Hythe Sands.

At the moment it is impossible to determine whether the above process was responsible for the formation of the hollow, often spherical, ferruginous concretions (boxstones) which occur elsewhere in the Lower Greensand. It is also impossible to assess the importance of pyrite as a source of the limonitic cement of carstone veins in formations such as the Folkestone Sands. These questions can only be answered when further information is available with regards to the distribution of pyrite and its undoubted alteration-products in the Lower Greensand. In this respect useful evidence should be forthcoming from deep-boring records since any pyrite beneath the zone of weathering and percolation by oxygenated water should be unaltered.

7. CONCLUSIONS

1. Pyrite nodules occur in the Middle Hythe Sands of the Tilburstow Hill area of Surrey.

2. The shattering of quartz-grains, and the high cement:grain ratio in the limonitic crusts of the nodules is due to pressures produced during the

alteration of pyrite. The behaviour of pyrite nodules in which the growth of melanterite is actually observed suggests that its formation could have been responsible for the observed phenomena.

3. The complete alteration of the pyrite nodules has led to the formation of hollow ferruginous concretions (boxstones) containing loose uncemented iron-stained sand. Iron salts diffusing from the nodules during their alteration may have contributed to the formation of carstone veins.

4. Further information regarding the distribution of pyrite in the Lower Greensand is very desirable.

ACKNOWLEDGMENTS

The author expresses his thanks to Drs. W. F. Fleet, W. S. Pitcher and A. F. Hallimond for their constructive criticisms of the ideas presented in this paper, and to Messrs. R. Webster, F.G.A., J. A. Gee and Miss S. Jackson for their help with the photography. He is also indebted to the late Dr. H. Simons for his assistance with the X-ray crystallography.

DESCRIPTIONS OF PLATES

Plate 2

Pyrite nodules from the Hythe Beds, Tilburstow Hill, Surrey.

A. Large pyrite nodule with a small portion of its limonitic crust removed.

B. Exceptionally irregular nodule.

C. Hollow limonitic concretion, full of incoherent iron-stained sand . . . a completely altered nodule.

D. Pyrite nodule after several months exposure to a moist atmosphere. Note the irregular cracks and the crustal fragments being thrown off by the growth of subcrustal melanterite (white).

E. Sectioned pyrite nodule showing crust and core, the latter traversed by a prominent vein of white selenite.

F. Typical spherical pyrite nodule collected *in situ*.

Plate 3

A. Polished section of core of pyrite nodule from the Middle Hythe Sands photographed under normal incident illumination. x 30.
Pyrite, white; sand-grains (quartz), grey.

B. Polished section of crust and part of core of pyrite nodule from the Middle Hythe Sands photographed under normal incident illumination. x 20.
Haematite (turgite), white; goethite, light grey; sand-grains (quartz), grey; pyrite, white grains as in Plate 3 A.
Note that the cement: grain ratio of the crust is much greater than that of the core seen in bottom left-hand corner of plate.

C. Thin section of the limonitic crust of the nodule shown in Plate 2 E. Photographed with transmitted light. x 60.
Sand-grains (quartz), white or light grey; limonite, black or dark grey.
Note the alignment of some of the limonitic veins traversing sand-grains.

REFERENCES

Bull, A. J. & F. Gossling. 1948. The structure of Tilburstow Hill. *Proc. Geol. Ass., Lond.*, **59,** 131–9.

Hallimond, A. F. 1925. Iron Ores: Bedded Ores of England and Wales. Petrography and Chemistry. *Spec. Rep. Min. Resour. G.B.*, **29,** *Mem. geol. Surv.*

Smith, L. L. 1948. Hollow Ferruginous Concretions in South Carolina. *J. Geol.*, **56,** 218–25.

The Sponge Genus *Retispinopora* in the English Chalk

by JOHN S. HAMPTON

Received 13 November 1956

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ABSTRACT: The history, stratigraphical distribution and possible zoological affinities of the Upper Cretaceous Sponge genus *Retispinopora* are briefly discussed. A new species, *R. tuberculata*, is described.

1. INTRODUCTION

DURING a recent investigation of a Chalk Rock fauna from Westerham, Kent (Hampton, 1955), a specimen of a new species of *Retispinopora* was collected. It is the first example of the genus to be recorded from the Upper Turonian, *Holaster planus* zone, of the Chalk in England.

2. GENUS *RETISPINOPORA* BRYDONE, 1912

Brydone (1912, p. 112) instituted *Retispinopora* for one of Lonsdale's forms of '*Spinopora dixoni*' from the Chalk of Sussex (1850, p. 264, pl. 18, fig. 39), and for two other species, *R. arbusculum* Brydone (1912, p. 113, pl. 3, figs. 30a–h, 31), from the zones of *Actinocamax quadratus* and *Belemnitella mucronata*, and *R. patula* Brydone (1912, p. 114, pl. 3, figs. 32a–c), from the *Offaster pilula* and *Actinocamax quadratus* zones of the Chalk of Hampshire. Gaster (1924, p. 99, fig. 7 (3, 3a)) erected a further species, *R. lancingensis*, for part of Brydone's *R. arbusculum* (1912, pl. 3, figs. 30f, g), stating that his new species was very characteristic of the *Hagenowia rostrata* horizon of the *Offaster pilula* zone of the Worthing district, and that it also occurred in the *Saccocoma cretacea* subzone of the *Actinocamax quadratus* zone. *R. columnaris* Brydone (1933, p. 290, footnote) is an exact synonym of *R. lancingensis* Gaster. In introducing the former, Brydone doubted whether *Retispinopora* was distinct from either *Spinopora* de Blainville or *Neuropora* Bronn, but his genus seems to lack characteristic features of the type species of those genera.

Retispinopora appears to be confined to the British Upper Cretaceous system, ranging from the Upper Turonian, *Holaster planus* zone, in Kent, to the uppermost Senonian, *Belemnitella mucronata* zone, in the Isle of Wight, where Brydone obtained a 'finely characterised specimen'. The best specimens, however, appear to come from the *Offaster pilula* and *Actinocamax quadratus* zones in Sussex and Hampshire.

de Laubenfels (1955, p. E107) referred *Retispinopora* to the 'unrecognizable supposed sponges', but an examination of Brydone's type-specimens in the Sedgwick Museum, Cambridge, and of Gaster's material in the British Museum (Natural History), has shown that the genus can be placed in the Porifera; its structure to some extent resembles that of the Chalk sponge *Porosphaera*, and if a relationship exists between these two genera it seems likely that *Retispinopora* was derived from *Porosphaera* in late Turonian times.

3. *RETISPINOPORA TUBERCULATA* sp. nov.

Text-fig. 1

1955. *Retispinopora* spp. (in part) Hampton, p. 45.

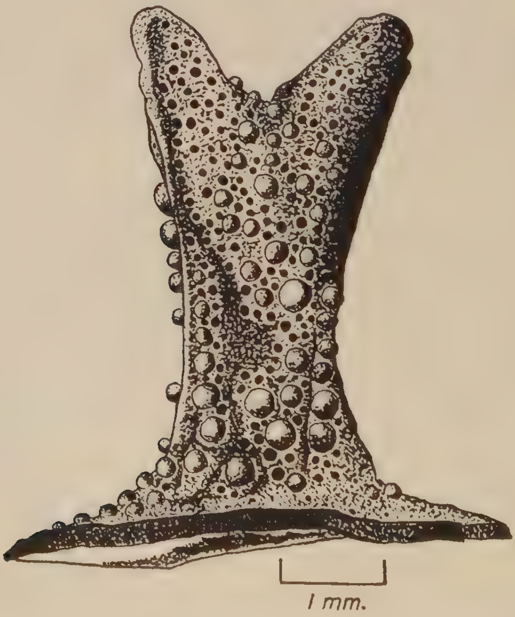

Fig. 1. *Retispinopora tuberculata* sp. nov. Camera lucida drawing of the holotype. B.M. (N.H.) S 7656

Material. One specimen, the holotype, British Museum (Natural History), Palaeontological Department, S 7656 (J. S. Hampton Colln.), from about one and a half miles NE. of Westerham Railway Station, Kent; Nat. Grid Ref. 51/449566.

Horizon. Upper Chalk (Upper Turonian), Chalk Rock, *Holaster planus* zone.

Diagnosis. *Retispinopora* with a wide, slightly concave, base and a narrower, short, stout stem, oval in cross-section, widening in its upper part into two short conical arms. Apex of the arms imperforate, smooth, but the remainder of the external surface with a reticulate structure of large, rounded tubercles and pores.

Description. The base has a roughened, but regular under-surface, forming a shallow depression. A strong smooth rib traverses each end of the longer axis of the stem, from just above the base to near the apex of the arms, ribs bounded on both sides by a line of well-developed rounded tubercles. The reticulate structure of the remaining external surface is irregular, the tubercles becoming smaller and dying out on the conical arms. Large pores are irregularly arranged between the tubercles.

Dimensions

Height	5.6 mm.
Greatest width of base	5.45 mm.
Axes of stem	1.82 mm. × 1.46 mm.
Maximum diameter of tubercles	0.228 mm.
Maximum diameter of pores	0.114 mm.

Remarks. *R. tuberculata* sp. nov. differs from all other species of the genus in possessing large, well-developed, rounded tubercles, in place of the characteristic spines, a wide irregular base and conical arms.

4. COMPARISON OF SPECIES

R. arbusculum Brydone: elongate, lower two-thirds cylindrical, upper one-third conical. Circular in cross-section. Ornamentation: apex imperforate, smooth, passing into a few strong, smooth radial ribs. Remainder a coarsely reticulate surface with stout spines.

R. patula Brydone: conical, circular in cross-section. Ornament identical with that of *R. arbusculum* Brydone, but with a concentric ornament on base.

R. lancingensis Gaster: stout, lower half cylindrical, upper half conical, circular in cross-section. Ornament identical with that of *R. arbusculum* Brydone.

R. tuberculata sp. nov.: wide base, short, stout stem, oval in cross-section, widening into two short conical arms. Ornament similar to that of

R. arbusculum Brydone, but well-developed, rounded tubercles replace the characteristic spines.

ACKNOWLEDGMENTS

I am indebted to Dr. T. Barnard for permission to use facilities in the Geological Department, University College, London; to Dr. H. Dighton Thomas, of the Palaeontological Department, British Museum (Natural History), for helpful criticism and advice during the preparation of this paper; to Mr. S. Ware for allowing me to examine specimens of *Retispinopora* and *Porosphaera* in the collections of the latter department; and to Mr. A. G. Brighton, of the Sedgwick Museum, Cambridge, for access to Brydone's type material.

REFERENCES

BRYDONE, R. M. 1912. *The Stratigraphy of the Chalk of Hants*. London.
————. 1933. The Zone of Granulated *Actinocamax* in East Anglia. *Trans. Norfolk Norw. Nat. Soc.*, **13** (3), 285–93.
GASTER, C. T. A. 1924. The Chalk of the Worthing District, Sussex. *Proc. Geol. Ass., Lond.*, **35** (2), 89–110, pl. 8, 1 table.
HAMPTON, J. S. 1955. An Exposure of Chalk Rock near Westerham, Kent. *Lond. Nat.*, **34**, 43–6.
DE LAUBENFELS, M. W. 1955. Archaeocyatha and Porifera. *Treatise on Invertebrate Paleontology* (R. C. Moore, Editor). Part E. Univ. Kansas Press.
LONSDALE, W., *in* DIXON, F. 1850. *Geology of Sussex*. London.

Field Meeting in the Clarendon Plains, Jamaica

JAMAICA GROUP

25 March 1956

Report by the Director: S. A. G. TAYLOR

Received 2 November 1956

THE AIM of this meeting was to demonstrate to members the progress that has been made in the development of the underground water resources of the Clarendon Plains, and especially the Mid-Clarendon Irrigation Scheme.

Twenty members and friends assembled in front of the Carib Theatre, Kingston, and proceeded to the office of the Mid-Clarendon Irrigation Scheme at Osborne Store, where they inspected a relief-map of the area and its water-shed, which made it clear why a large volume of underground water passes beneath the Plains.

From Osborne Store the party proceeded to St. Toolies where they saw the intake on the Milk River, and the Milk River No. 2 Well delivering 2,000,000 gallons of water a day into the system. They then walked along the canal and saw the St. Toolies No. 2 and St. Toolies No. 1 Wells delivering 4,000,000 and 3,000,000 gallons a day, respectively, into the system. They continued to St. Toolies No. 3, which was started-up for the benefit of members. This borehole, in which a 150 h.p. motor and deep-well pump is installed, discharged a flow of 7,000,000 gallons a day.

The party then had lunch and proceeded to the St. Jago Well, which is equipped with a 200 h.p. motor and deep-well pump capable of delivering 5,000,000 gallons a day into the old Milk River canal system, when pumping against a head of 130 feet.

From St. Jago the party drove to York Pen and saw a 24-inch borehole well being drilled to supply a new area with water for irrigation. At the time of the visit the boring had reached a depth of 430 feet. After passing through 80 feet of recent alluvium and 220 feet of dense marine clays, the borehole had struck limestone rock at 300 feet. It was expected that the main aquifer would be struck at 500 feet. This borehole penetrates the buried valley.

Unfortunately, at this point heavy rain began to fall, and, as a result, it was necessary to abandon the visit to the ruins of the dam at Raymonds. Three and a half inches of rain fell in two hours, causing some members to ask the Director why he considered it necessary to drill hundreds of feet underground when there was so much water on the surface. They were assured that this surface water was unusual. The party then stopped at the Cockpit Pumping Station and was shown over the works by Mr. Harold Archer, Irrigation Engineer of the West Indies Sugar Company. On their way home they passed the springs of the Cockpit River which are intercepted by a low-level canal leading to the Pumping Station.

Field Meeting at the Kirkvine Works of Alumina Jamaica Limited

JAMAICA GROUP

29 July 1956

Report by the Director: D. A. BRYN DAVIES

Received 2 November 1956

THE MAIN PARTY met in front of the Carib Theatre, Kingston, and drove to Shooters Hill near Mandeville, where they were joined by members and friends from other parts of the island. The whole group, numbering forty-two, assembled in the General Office, Kirkvine Works, at 10.30 a.m. Here the Director, in the name of Alumina Jamaica Limited, greeted the members of the Association and their guests.

Mr. S. M. Patterson, Works Manager, outlined the main steps in the process of alumina manufacture—bauxite mining, grinding and slurrying, digestion at high temperature and pressure with caustic soda, clarification by settling, followed by filtration, precipitation of alumina hydrate from the clear liquor, and calcination in rotary kilns to alumina. Brief reference was also made to lime production for reaction with soda ash to produce caustic soda, and to the transportation and shipment of the alumina in bulk from Port Esquivel. (The latter installation of the Company had previously been visited by the Association.)

The party first visited the quarry in the White Limestone Formation, of Lower Miocene age, about one and a half miles from the alumina plant, and then made a tour of the bauxite mines which are about the same distance away. Open-cast mining with diesel drag-lines and loading into 20-ton haulage units were seen. A visit was also made to the tailings ponds where the 'red mud' residue from the alumina process is disposed of in mined-out areas.

For the visit to the plant itself, the party split into three sections, guided respectively by the Director, Mr. Patterson and Mr. J. G. Wright (Chief Chemist). The main points of interest visited were the bauxite storage and grinding building, the precipitator tanks, reached by a ninety-foot elevator, and the calcining kilns. The power-house, supplying heat and power for the process from fuel oil, was also seen.

The plant being in process of expansion from a capacity of 210,000 tons of alumina per annum to 500,000 tons per annum, various phases of construction activity were seen *en route*.

Reunited at the office after the tour, the party then proceeded to the Mandeville Hotel, where the Association were guests of the Company at a rather late luncheon. Dr. L. J. Chubb then proposed a vote of thanks to the Company, to which Dr. Bryn Davies replied.

Field Meeting in the Oxford Clay of Calvert and Woodham Brick Pits, Buckinghamshire

23 September 1956

Report by the Director: J. H. CALLOMON

Received 31 December 1956

AT CALVERT, six miles east of Bicester, the Lower Oxford Clay is worked for bricks in huge excavations to a depth of about fifty feet. The section has so far not been described in detail, but the beds normally worked are confined to the *coronatum* Zone of the Middle Callovian; occasionally, lower beds (*jason* and *calloviense* Zones) are exposed in drainage trenches (Callomon, 1955, p. 243; zonal classification of the Callovian, p. 256). The pit at Woodham, on the main road half-way between Bicester and Aylesbury, shows about seventy feet of the Middle Oxford Clay, including the *athleta* and *lamberti* Zones of the Upper Callovian, and *mariae* Zone of the Lower Oxfordian. The section and faunas were described by Arkell (1939, 1947).

Although these two sections are important stratigraphically, their main attraction lies in the profusion of ammonites which they produce. It was thought that, besides demonstrating the stratigraphical sequence, the material collected during a visit might be used to illustrate some of the characteristics of ammonites and how these characteristics can be used to best advantage. With this end in mind, some notes on the ammonites had been prepared and duplicated beforehand by the Director, and copies distributed to the members of the party. The following are some extracts:

> (a) *Morphology*. It appears that ammonites, unlike many other marine creatures, did not continue to grow until death but attained a mature stage at which growth stopped. The size of the shell at this stage is often closely defined in any one species. As the largest proportion of intact shells found in a bed normally consists of these mature adults, the conclusion seems inescapable that ammonites spent a good part of their lives in the adult stage. The signs of maturity to be looked for are:
>
> (i) Uncoiling of the umbilical seam.
>
> (ii) Modification of the ribbing near the body-chamber aperture, usually a coarsening, with sometimes a process, e.g. a lappet on each side. Lappets are exclusively adult features.
>
> (iii) Approximation and degeneration of the last few septal sutures.
>
> (b) *Facies*. The corraline is the only marine facies in which ammonites do not occur but other facies can have lesser influences. Thus, in some

clays most of the ammonites found are immature, forming so-called micromorphic faunas. Examples of this can be seen in the clay beds at Woodham. Most of the pyritised nuclei are those of immature shells with non-pyritised body-chambers, although the same species occur in mature form in beds of similar age in Yorkshire and the Hebrides. The faunas of the limestone, bed C, and of the clays at Calvert, are normal. The small pyritised fauna, though so beautifully preserved, is largely useless for systematic studies. (The facies at Woodham are also discussed by Rutten, 1956.)

(c) *Dimorphism*. When attempts are made to classify a collection of adult ammonites of any one genus into species, it frequently happens that the shells can be clearly divided into two groups. Those of the one group are generally much larger than those of the other, often twice as large or more. The body-chambers tend to lose their ornamentation, and frequently become quite smooth; the body-chamber aperture is usually gently sinuous. The shells of the second group, besides being smaller, are strongly ribbed to the end and often bear lappets or a long ventral rostrum on the aperture. That these two groups are intimately related is shown by the fact that inner whorls of both are often so similar as to be indistinguishable. They may be conveniently called macro- and microconchs, respectively. The large number of cases in which this division has now been recognised suggests some profound underlying significance, i.e. that ammonites were dimorphic; and there seems no overriding reason against assuming the cause to have been sexual. Among the first to recognise this dimorphism systematically was Waagen in 1869.

(d) *Faunal provinces*. Coinciding with a regression in the Bathonian stage, followed by a major transgression at the beginning of the Callovian, the ammonites of the world separated into faunal realms having hardly a genus or species in common. Correlation is possible in the regions of overlap. Great Britain lies in one such region, that between the Boreal (Arctic) and Tethyan (Mediterranean) realms; each has its own fauna, of which those found at Calvert and Woodham are mixtures.

A coach left Charing Cross Station at 9.15 a.m., and the party, consisting of the President and some fifty members and friends, assembled at Calvert pit two hours later. An hour's collecting from section and tip-heaps produced several dozen ammonites, including the following:

CORONATUM ZONE:

Kosmoceras (*Gulielmites*) *effulgens* (Buckman)
  (*Zugokosmokeras*) *obductum* (Buckman) (index of the *obductum* Subzone)
  (*Zugokosmokeras*) *grossouvrei* (Douvillé) (index of the *grossouvrei* Subzone)
  (*Gulielmiceras*) aff. *gulielmi* (Sowerby)
  (*Spinikosmokeras*) *castor* (Reinecke)
Erymnoceras cf. *reginaldi* (Morris) and sp., three specimens
Peltoceras sp. undescribed, one specimen

JASON ZONE:

Kosmoceras (*Gulielmites*) *jason* (Reinecke), one specimen in a block from a stone band exposed in a drainage trench.

The *Peltoceras*, only partly crushed and about 200 mm. in diameter, showed features transitional to the Pseudoperisphinctidae (from which the genus is thought to have evolved) but had inner whorls of typical angular cross-section. Its occurrence in the *coronatum* Zone is of interest, as it has hitherto not been recorded from below the overlying *athleta* Zone.

The signs of maturity could be clearly seen in the Kosmoceratids, although most were crushed flat. Mature examples were sufficiently numerous to show the constancy of the diameter of fully grown shells, and these could be easily divided into macroconchs (*Gulielmites*, *Zugokosmokeras*) and microconchs (*Gulielmiceras*, *Spinikosmokeras*). The size-ratio was a factor of about two, and several of the microconchs bore lappets. The difficulty in distinguishing inner whorls of both groups could be seen in broken and incomplete material.

After lunch, two hours' collecting at Woodham yielded an even larger number of ammonites, mostly found lying loose or on tip-heaps. The greater number came from the *lamberti* Limestone, bed C, and were indifferently preserved, but the micromorphic uncrushed pyritic or limonitic fauna from the clay beds was also well represented. Many of the species described by Arkell could be identified. A notable find was a specimen of *Phylloceras* (*Calliphylloceras*) *demidoffi* (Rousseau) from bed A, found by J. M. Hancock, the excursion secretary. It is the second found at Woodham (the first was exhibited at the Association's conversazione in 1937), and one of the very few examples of *Phylloceras* known in this country from between the Upper Lias and Cretaceous.

The many *Quenstedtoceras* from bed C could again be divided into macroconchs (subgenus *Eboraciceras*) and microconchs (*Quenstedtoceras* s.s.). The contrast here is greater than in *Kosmoceras*, for *Eboraciceras* becomes large and quite smooth, with very markedly contracted body-chamber and uncoiling of the umbilical seam. The compositions of the faunas found at Calvert and in the *lamberti* Limestone at Woodham were compared. That at Calvert consisted overwhelmingly of *Kosmoceras* of Boreal habitat; whereas in the *lamberti* Limestone, although the predominant single element *Quenstedtoceras* is also of Boreal origin, others, e.g. Oppeliidae, Perisphinctidae, *Peltoceras*, *Aspidoceras* and especially *Phylloceras*, are of Mediterranean type and together make up probably fifty per cent of the total fauna. In the *mariae* Zone above, Boreal elements again predominate.

The meeting came to a close at about 5 p.m. Before dispersing, the President expressed the thanks of the party to the Director for an interesting excursion and, after a stop for tea at Aylesbury, the coach took members back to London.

It is a pleasure to thank the Directors of the London Brick Company and the Woodham Brick Company for permission to visit the two pits.

REFERENCES

ARKELL, W. J. 1939. The ammonite succession at the Woodham Brick Company's pit, Akeman Street Station, Buckinghamshire, and its bearing on the classification of the Oxford Clay. *Quart. J. geol. Soc. Lond.*, **95**, 135.

———. 1947. *The Geology of Oxford*. Oxford University Press.

CALLOMON, J. H. 1955. The ammonite succession in the Lower Oxford Clay and Kellaways Beds at Kidlington, Oxfordshire, and the zones of the Callovian stage. *Phil. Trans.*, ser. B, **239**, 215.

RUTTEN, M. G. 1956. Depositional environment of Oxford Clay at Woodham clay pit. *Geologie en mijnbouw*, **18**, 344.

Field Meeting in the Cliviger Gorge

NORTH-EAST LANCASHIRE GROUP

8 September 1956

Report by the Director: I. A. WILLIAMSON

Received 30 November 1956

THE FIELD MEETING was arranged to enable members to study the upper beds of the Millstone Grit Series exposed on the western side of the Cliviger Gorge, some five miles south-east of Burnley.

During the morning the succession of Green's Clough, at Portsmouth (SD/897264), was examined. This stream gives a particularly well-exposed section, the various sandstones in the upper part of the Millstone Grit Series being the fallmakers for a succession of waterfalls. The sandstones, separated largely by shales and shaley mudstones, are:

		Gastrioceras subcrenatum
	Rough Rock	
	Upper Haslingden Flags	
		Gastrioceras cumbriense
	Lower Haslingden Flags	
		Gastrioceras cancellatum
Middle Grits	Holcombe Brook Grit	
		Reticuloceras superbilingue
	Hazel Greave Grit	
	Helmshore Grit	
	Gorpley Grit	

The fossil names given are those of the characteristic goniatite found in bands of marine shale which occur above many of the 'grits'. (The stratigraphical term 'grit' does not necessarily imply a coarse sandstone, wide textural variations in the sandstones are common.)

The Gorpley Grit is exposed at the base of the stream just above the Portsmouth Mill, and also in the prominent escarpment in Cock Hill Wood (SD/900260),[1] above the recreation ground. At both these localities the grit is coarse and rather massive. A thin sandstone series, in which some ripple marked flaggy beds are seen, forms the local equivalent of the Helmshore Grit of the Rossendale area to the east.

The overlying Hazel Greave Grit outcrops in a large waterfall (SD/895263), at the top of which is exposed the associated marine band and also a thin shale band packed with fish-scales.

The Holcombe Brook Grit is the next fallmaker (SD/895262). The 'grit' is a medium sandstone above which is a development of sandy mudstones and fireclays. Associated with the overlying marine beds are thin beds of contorted shale. These are considered by the Director to indicate some tectonic movement (Williamson, 1953). A similar association of marine band and contorted shale is also seen above the Lower Haslingden Flags.

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[1] Editor's Note. SD/...... is the Ordnance Survey code letters representing the figures 34/......

The Lower Haslingden Flags are well exposed upstream (SD/894261), where they are thirty-five feet thick, a marked decrease in thickness from the 100 feet of flags in the Rossendale Valley several miles to the south-west. The overlying marine band outcrops in the shale bluff on the north side of the clough, about ten feet above the flags.

In contrast to sections in the Cliviger Gorge to the north and west of Green's Clough, the Upper Haslingden Flags are more easily recognised here, being separated by shale and shaley mudstones from the overlying Rough Rock. Unfortunately, the horizon immediately above the flags yielding *Anthraconaia bellula*, recorded in 1890 by Bolton, has not so far been rediscovered in Green's Clough. Both the Rough Rock and Upper Haslingden Flags form well-marked features and below the outcrop of the latter, on the south bank of the clough, is a striking landslipped mass of flaggy beds. The stream gives a continuous section in the Rough Rock, a sandstone of variable texture. This bed, in other parts of the Cliviger Gorge, is split into two leaves by a thin coal, the 'Sand Rock Mine', but in Green's Clough this is absent. Below the uppermost waterfall in the Rough Rock (SD/892260), a north-west trending joint is seen in both sides of the clough, with a three-inch-thick barytes infilling.

The upper reaches of the clough are in the Lower Coal Measures, though only the Woodhead Hill Rock is now exposed owing to recent open-cast and underground mining. The principal seam is the 'Lower Mountain' or 'Union Mine', which is at present being worked from the Hill Top Drift at the head of the clough. The seam was formerly worked by open-cast methods along its outcrop upon Heald, and Carr and Craggs Moors. This site was not fully restored and much of the area now provides good miniature examples of soil-wash and badland topography.

After lunch, the party proceeded to the head of Ratten Clough (SD/880266), where the *Gastrioceras subcrenatum* marine band, the base of the Lower Coal Measures, and also a contorted shale, outcrops. The Rough Rock escarpment upon the immediate south of the clough displays excellent camber due to landslipping into the Cliviger Gorge. From here the effect of the Cliviger Valley Fault, downthrowing some 1300 feet to the east, is well marked. The escarpments upon the opposite side of the Cliviger Gorge are formed by Lower and Middle Coal Measure sandstones which are thrown against the Middle Grits of the western (Ratten Clough) side.

The top of the Rough Rock escarpment was then followed round to Fair Hill (SD/886270), where the precipitous fault line escarpment of Thieveley

Scout is well seen. This is composed of three main features formed by the Woodhead Hill Rock in the Lower Coal Measures, and the Rough Rock and Lower Haslingden Flags in the Millstone Grit Series. The outcrop of the Sand Rock Mine makes a small feature near the top of the Rough Rock.

The overdeepened nature of the Cliviger Gorge is most apparent in the view south-west from Fair Hill. During a retreat of the ice margin from the district, the valley operated as a direct overflow channel for a series of pro-glacial lakes on the Pennine moorlands to the north-west. The gentle slopes of the remnants of the pre-glacial valley contrast greatly with the canyon-like outline of the present valley.

Thieveley Scout was descended by Fish Pond Clough (SD/877275). At the head of the clough the Woodhead Hill Rock, a fine grained yellow sandstone, shows well-developed current bedding. Above the Rough Rock is the 'Six Inch Mine', at this locality one foot six inches thick, and succeeded by the *Gastrioceras subcrenatum* marine band. The 'Sand Rock Mine' in the Rough Rock is seen on the east side of the clough where the coal is one foot two inches thick.

After passing the site of the Thieveley Lead Mines, the relics of a series of uneconomic mining ventures in the seventeenth and eighteenth centuries, the party descended to Holme Chapel. Refreshments were had at the Ram Inn and the meeting was concluded after a vote of thanks to the Director had been moved by Mr. J. Ranson, the chairman of the Group.

REFERENCES

BOLTON, H. 1890. *The Geology of Rossendale.*

WILLIAMSON, I. A. 1953. Intraformational Contorted Strata in the Upper Carboniferous of the Lancashire Pennines. *Proc. Yorks. geol. (polyt.) Soc.*, **29**, 149–60.

————. 1956. Field Guide to the Geology of the Cliviger Valley. *Proc. Yorks. geol. (polyt.) Soc.*, **30**, 375–406.

WRIGHT, W. B., *et al.* 1927. The Geology of the Rossendale Anticline. *Mem. geol. Surv. U.K.*

The Annual Report of the Council of the Geologists' Association for the Year 1956

THE NUMERICAL STRENGTH of the Association on 31 December 1956, was as follows:

Honorary Members	19
Ordinary Members:	
Life Members (compounded) ...	171
Annual Subscribers	1688
Institutional Members	55
	1933

During the year 140 new members were elected, and the Association lost 128 members through death, resignation and removals under Rule XI for failure to pay subscriptions. Four members were reinstated.

Thus the membership has increased by sixteen.

The list of deceased members is as follows: J. C. Andersen, H. G. Busk, W. N. Edwards (Hitchin), H. B. Harwood, W. E. Howarth, Duncan Leitch, H. L. Sargent, George Slater, Frederick Smith, Sir Arthur Trueman and R. F. L. White. (D. S. Haig and S. M. Martin, 1955.) A. G. Davis.

Obituary Notices are published on pages 95–106.

FINANCE

There was a slight improvement in subscription income although the arrears were still too high. The conservative valuation placed on the 1955 arrears was not realised. Sales of publications improved and nearly reached the 1954 figure.

The Council of the Royal Society made a Parliamentary Grant-in-Aid of Scientific Publications of £200. This was not actually received in 1956 but has been carried back into the accounts.

Sharp rises in Printing cost have taken place during the year as well as an increase in Postal Rates, the two items which constitute the major part of the Association's expenditure. The final result was a deficit for the year of £355 16*s*. 8*d*., which has been met by transferring the balances of the income of the Compounding Fund and the Bequest Fund and still further reducing the balance of the accumulated income from previous years.

(This was formerly shown in the accounts as the 'General Reserve' but is now brought forward as the balance of the 'Income and Expenditure' Account.)

Two items in the accounts need explanation. The amount under Printing and Stationery in the General Expenses (Statement 2) does not include the cost of the List of Members issued early in the year; this is charged against the Indexing Fund, and the reserve of £1200 for the two double parts of the PROCEEDINGS for 1956, which will have to be borne in 1957, is included in the 'Accrued Expenses' in Statement 1, and as part of the 'estimated' figure in Statement 2.

Under the will of the late W. E. Howarth the Association received a Legacy of £100 for the Capital of the Illustrations Fund which has been invested in British Electricity Stock, and a further sum of £1021 5*s.* Seven hundred pounds of this was received in 1956 and the balance, partly in cash and partly in Post War Credits, has since come to hand.

During the year the Trustees recommended the investment in British Electricity Stock of £200 of the Bequest Fund then in the P.O. Savings Bank and also £200 of the Compounding Funds. This has been done.

BALANCE SHEET AT 31 DECEMBER 1956

Statement 1

1955 £		£ s. d.	£ s. d.	£ s. d.
	TRUST FUNDS AND FUNDS FOR SPECIAL PURPOSES:			
5512	Capital: (Invested)		6011 12 4	
68	(Uninvested)		700 0 0	
5580				6711 12 4
	Accumulated Income:			
342	Bequest Fund (Statement 3) ...		5 5 4	
81	Centenary Fund (Statement 4)		123 14 10	
138	Compounding Fund (Statement 5)		6 18 4	
–	Illustrations Fund (Statement 6)		– – –	
222	Indexing Fund (Statement 7) ...		12 16 4	
155	Watts Charnwood Forest Fund (Statement 8)		157 11 3	
27	Foulerton Award Fund (Statement 9)		15 2 0	
63	G. W. Young Geological Investigation Fund (Statement 10)...		70 9 6	
37	Henry Stopes Memorial Fund (Statement 11)		45 1 2	
22	Miss M. S. Johnston Legacy (Statement 12)		64 18 0	
1087				501 16 9
6667				7213 9 1
	GENERAL FUNDS:			
569	Income and Expenditure Account (Statement 2)			494 5 1

1955 £		£ s. d.	£ s. d.	£ s. d.
	TRUST FUNDS AND FUNDS FOR SPECIAL PURPOSES:			
5512	Investments (Statement 13) ...			6011 12 4
13	Income Tax Recoverable ...		16 2 1	
1142	Cash at Bank and Post Office ...		1185 14 8	
1155				1201 16 9
£6667				£7213 9 1
	GENERAL FUNDS:			
	Debtors:			
–	Royal Society Grant	200 0 0		
9	Post Office Interest	17 0 0		
200	Subscription in Arrears ...	150 0 0		
20	Admission Fees in Arrears ...	– – –		
			367 0 0	
1972	Cash at Bank, Post Office and in Hand		1558 10 10	
2201			1925 10 10	
89	*Less* Subscriptions in Advance	91 10 5		
1543	*Less* Accrued Expenses ...	1339 15 4		
1632			1431 5 9	

1955 £	EXPENDITURE	£ s. d.	£ s. d.
1660	'PROCEEDINGS' OF THE ASSOCIATION (ESTIMATED)		1638 12 7
	GENERAL EXPENSES:		
37	Accountancy	36 15 0	
–	Addressing and Stock-keeping	9 7 2	
14	Field Meetings Expenses	– – –	
3	Insurance	3 13 11	
62	Meetings Expenses	66 17 3	
172	Postages	288 6 1	
147	Printing and Stationery	90 10 4	
250	Printing Monthly Circulars	307 12 6	
6	Sundries	2 3 10	
31	Typing and Duplicating	18 8 6	
722			823 14 7
2382			2462 7 2
100	TRANSFER TO INDEXING FUND		– – –
£2482			£2462 7 2
228	DEFICIT FOR YEAR BROUGHT DOWN		355 16 8
569	BALANCE per Balance Sheet (Statement 1) ...		494 5 1
£797			£850 1 9

1955 £	INCOME	£ s. d.	£ s. d.
	ANNUAL SUBSCRIPTIONS RECEIVABLE:		
1468	Received for 1956	1494 10 6	
177	Received for previous years	117 0 0	
200	*Add* Arrears at 31 December 1956 £294 estimated to realise	150 0 0	
1845		1761 10 6	
250	*Less* Arrears at 31 December 1955 £518 8 0 estimated to realise	200 0 0	
1595			1561 10 6
	ADMISSION FEES RECEIVABLE:		
74	Received for 1956	71 10 0	
1	Received for previous years	1 0 0	
20	*Add* Arrears at 31 December 1956	– – –	
95		72 10 0	
3	*Less* Arrears at 31 December 1955	20 0 0	
92			52 10 0
9	POST OFFICE INTEREST		25 0 0
–	PROFIT ON FIELD MEETINGS		1 10 3
300	ROYAL SOCIETY GRANT: 1956		200 0 0
209	PUBLICATIONS SALES		237 3 9
49	TRANSFER FROM ILLUSTRATIONS FUND (Statement 6)		28 16 0
228	DEFICIT FOR YEAR CARRIED DOWN		355 16 8
£2482			£2462 7 2
429	BALANCE, 1 January 1956		569 7 8
368	TRANSFER FROM GENERAL RESERVE		– – –
–	TRANSFER FROM COMPOUNDING FUND (Statement 4)		102 14 5
–	TRANSFER FROM BEQUEST FUND (Statement 3) ...		177 19 8
£797			£850 1 9

FUNDS FOR SPECIAL PURPOSES

BEQUEST FUND

Statement 3

	£	s.	d.		£	s.	d.
Purchase of Investment	200	0	0	Balance, 1 January 1956	341	19	8
Transfer to Income and Expenditure Account	177	19	8	Investment Income (Statement 13)	41	5	4
Balance, 31 December 1956 (per Balance Sheet)	5	5	4				
	£383	5	0		£383	5	0

CENTENARY FUND

Statement 4

	£	s.	d.		£	s.	d.
Postage and Duplicating		13	6	Balance, 1 January 1956	80	18	1
Balance, 31 December 1956 (per Balance Sheet)	123	14	10	Investment Income (Statement 13)	43	10	3
	£124	8	4		£124	8	4

COMPOUNDING FUND

Statement 5

	Uninvested Capital £	s.	d.	Income £	s.	d.		Uninvested Capital £	s.	d.	Income £	s.	d.
Transfer to Capital				96	0	0	Balances, 1 January 1956	68	0	0	138	9	6
Transfer to Income and Expenditure Account ...				102	14	5	Investment Income (Statement 13)				67	3	3
Purchase of Investment	200	0	0				Compounding Fees Received	36	0	0			
Balance, 31 December 1956 (per Balance Sheet) ...				6	18	4	Transfer from Income	96	0	0			
	£200	0	0	£205	12	9		£200	0	0	£205	12	9

FUNDS FOR SPECIAL PURPOSES (*Continued*)

Statement 6

ILLUSTRATIONS FUND

	£	s.	d.		£	s.	d.
Transfer to Income and Expenditure Account	28	16	0	Investment Income (Statement 13)		12	6
				Donations and Subscriptions	28	3	6
	£28	16	0		£28	16	0

Statement 7

INDEXING FUND

	£	s.	d.		£	s.	d.
Printing and Stationery Expenses	208	17	6	Balance, 1 January 1956	221	13	10
Balance, 31 December 1956 (per Balance Sheet)	12	16	4				
	£221	13	10		£221	13	10

Statement 8

WATTS CHARNWOOD FOREST FUND

	£	s.	d.		£	s.	d.
Balance, 31 December 1956 (per Balance Sheet)	157	11	3	Balance, 1 January 1956	154	19	0
				Sales of Books	2	12	3
	£157	11	3		£157	11	3

FOULERTON AWARD FUND

Statement 9

	£	s.	d.		£	s.	d.
Award to Mr. D. F. W. Baden-Powell	10	0	0	Balance, 1 January 1956	27	5	5
Printing of Certificates for Awards	12	13	0	Investment Income (Statement 13)	10	9	7
Balance, 31 December 1956 (per Balance Sheet)	15	2	0				
	£37	15	0		£37	15	0

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND

Statement 10

	£	s.	d.		£	s.	d.
Income Tax Repaid to Public Trustee	5	17	2	Balance, 1 January 1956	62	10	9
Balance, 31 December 1956 (per Balance Sheet)	70	9	6	Interest Received from Public Trustee (Gross)	13	15	11
	£76	6	8		£76	6	8

HENRY STOPES MEMORIAL FUND

Statement 11

	£	s.	d.		£	s.	d.
Balance, 31 December 1956 (per Balance Sheet)	45	1	2	Balance, 1 January 1956	37	1	8
				Investment Income (Statement 13)	7	19	6
	£45	1	2		£45	1	2

MISS M. S. JOHNSTON LEGACY

Statement 12

	£	s.	d.		£	s.	d.
Balance, 31 December 1956 (per Balance Sheet)	64	18	0	Balance, 1 January 1956	21	12	8
				Investment Income (Statement 13)	43	5	4
	£64	18	0		£64	18	0

Statement 13

SCHEDULE OF INVESTMENTS—31 DECEMBER 1956

	AT COST OR VALUE WHEN ACQUIRED		INVESTMENT INCOME (GROSS)	
	£ s. d.	£ s. d.	£ s. d.	£ s. d.
FUNDS FOR SPECIAL PURPOSES:				
Bequest Fund:				
£143 8 9 3½% War Stock	141 14 0		5 0 6	
£150 0 0 New Zealand 3½% Stock 1960/64	122 5 0		5 5 0	
£85 0 0 3% Defence Bonds	85 0 0		2 11 0	
£200 0 0 3½% Defence Bonds (converted from 3% in January 1955)... ...	200 0 0		7 0 0	
£100 0 0 3% Savings Bonds 1960/70 ...	100 0 0		3 0 0	
£441 5 4 3% British Transport Stock 1978/88	400 0 0		13 4 10	
£224 13 3 4¼% British Electricity Stock	200 0 0	1248 19 0	5 4 0	41 5 4
Centenary Fund:				
£1000 0 0 4½% Defence Bonds (converted from 3½% in June 1956)		1000 0 0		43 10 3
Compounding Fund:				
£1217 2 6 Nottingham Corporation 3% Irredeemable Stock	1152 13 2		36 10 2	
£200 0 0 3% Savings Bonds 1955/65 ...	200 0 0		6 0 0	
£170 0 0 3½% War Stock	152 14 5		5 19 0	
£100 0 0 3% Savings Bonds 1965/75 ...	100 0 0		3 0 0	
£300 0 0 3½% Treasury Stock 1977/80...	282 2 0		10 10 0	
£224 13 3 4¼% British Electricity Stock	200 0 0	2087 9 7	5 4 0	67 3 3
Illustrations Fund:				
£21 0 10 Metropolitan Water Board 3% 'B' Stock	20 0 0		12 6	
£113 13 1 4¼% British Electricity Stock	100 0 0	120 0 0	– – –	12 6
TRUST FUNDS:				
Foulerton Award Fund:				
£349 7 0 3% British Transport Guaranteed Stock 1978/88		294 11 0		10 9 7
Henry Stopes Memorial Fund:				
£265 19 2 Government of Newfoundland 3% Stock 1943/63		260 12 9		7 19 6
LEGACY:				
Miss M. S. Johnston:				
£1236 4 6 3½% War Stock		1000 0 0		43 5 4
TOTAL INVESTMENTS, per Balance Sheet		£6011 12 4		

MARTIN, FARLOW & CO., *Incorporated Accountants.*

We have compared these Statements with the books and records presented to us and find them to agree.

We have also verified the Investments and Cash Balances held by the Association at 31 December 1956.

L. J. PITT, *Treasurer*
February 1957.

J. SUTTON } *Auditors*
CHAS. F. TOZER }

PUBLICATIONS

Publications Committee. The Committee consisted of the seven officers with Mrs. E. M. Evans and Messrs. E. E. S. Brown, S. E. Hollingworth, John Sutton, H. Dighton Thomas and Gilbert Wilson.

The Committee met on five occasions and considered fifteen papers on which reports were made to Council.

Proceedings. The four parts of Volume 66 (for 1955) were published during the year. Parts 1 and 2 were issued in a combined form. The number of pages was 374, and there were eleven plates.

For financial reasons it was decided that advertisements should be included in the PROCEEDINGS from the first part for 1957.

It is expected that all the parts for 1956 will be published early in 1957.

MEETINGS

Nine Ordinary Meetings were held at which seven papers were read, two papers were taken as read and one lecture given.

The thanks of the Association are due to the authors of papers and the lecturer and to the Geological Society for use of its apartments throughout the year.

REUNION

The Annual Reunion was held at the Chelsea Polytechnic on Saturday, 3 November. A wide range of exhibits was shown and it was attended by about 350 members and friends.

Thanks are due to the Principal and staff of the Polytechnic and the members concerned.

FIELD MEETINGS

The Committee consisted of the seven officers with Messrs. D. V. Ager, D. F. W. Baden-Powell, D. Curry, A. G. Davis, J. M. Hancock, J. F. Kirkaldy, H. M. Montford, W. S. Pitcher and W. E. Smith.

Seven Demonstrations, three weekend, six whole day and two half-day Field Meetings were held during the year.

Easter and Whitsun Field Meetings were held in Jersey and the Gloucester–Ledbury–Malvern region respectively.

The Lower and Upper Palaeozoic Rocks of the North Crop of the South Wales Coalfield were visited for the Summer Long Field Meeting.

The thanks of the Association are due to the Directors and all others who organised and assisted at these meetings.

THE LIBRARY

The Library Committee consisted of the President, the Librarian, Mrs. Evans, Messrs. L. R. Cox, M. K. Wells, Gilbert Wilson and J. W. Scott, Librarian of University College, London.

The Association gratefully acknowledges the gifts of books and pamphlets listed in the Session's Report.

An exchange of publications has been instituted with the following: U.S.S.R. Academy of Sciences, Moscow; State Lenin Library, Moscow; Slovene Academy, Bratislava, Czechoslovakia.

NORTH-EAST LANCASHIRE GROUP

Chairman: J. Ranson, A.M.I.Min.E., F.G.S.

Secretary: Mrs. J. F. Ranson, B.A.

Committee: D. H. Learoyd, N. Thompson, S. Westhead, I. A. Williamson.

During the year six meetings were held and there were eight Field Meetings. Particulars are published in the Report of the Session.

Thanks are due to the Blackburn Education Authority and the Governors and Principal of the Blackburn Technical College for the use of rooms.

MIDLAND GROUP

Chairman: A. Ludford, M.SC., F.G.S.

Secretary: I. Strachan, Ph.D., F.G.S.

Committee: A. J. Aiers, A. F. Archer, P. A. Garrett, D. R. Hughes, Professor F. W. Shotton, C. S. Tighe.

During the year five meetings were held in the Geology Department, The University, Birmingham, and there were four Field Meetings. Particulars are published in the Report of the Session. Thanks are due to Professor Shotton for the use of the Geology Department at the University for these meetings.

NORTH STAFFORDSHIRE GROUP

Professor F. Wolverson Cope, D.SC., F.G.S.

Chairman: J. T. Wattison, F.G.S., F.R.E.S.

Vice-Chairman and Chairman-Elect for 1957–9: P. S. Keeling, B.SC., A.R.S.M., F.G.S.

Secretary: T. S. Purcell, B.SC.

Treasurer: J. T. Gleaves, B.A.

Field Secretary: T. S. Jones, F.G.S.

Research Secretary: D. O. Thomas, F.G.S.

Committee: Miss I. Cottier, Dr. C. S. Exley, M.A., D.Phil., F.G.S., Messrs. J. Myers, B.SC., F.R.G.S., F.G.S., J. C. Parrack, B.SC., F.R.G.S., E. A. Watkin.

During the year 1956 seven Ordinary Meetings, and the Annual Conversazione, were held. Field and Research Group Meetings totalled six. After its 1956 Annual Meeting, the Critical Geological Sections Committee of the British Association made a grant to the Group for the investigation of the Red Rock Fault. This work is organised by the Research Section.

JAMAICA GROUP

Chairman: L. J. Chubb, M.SC., Ph.D., F.G.S.
Vice-Chairman: A. G. Taylor.
Secretary: J. B. Williams, B.SC., F.G.S.
Treasurer: M. B. C. Scott.
Committee: Kathleen O. Cusack, Eric L. Frater, Dr. G. V. Helwig, Harry E. Vendryes.

During the year (1956) four meetings were held, and there were six Field Meetings. Particulars are published in the Report of the Session. Thanks are due to the Institute of Jamaica for the use of rooms.

TRUSTEES

The Trustees of the Association were:

Managing: Mr. S. Hazzledine Warren, F.G.S., Dr. W. F. Fleet, M.SC., A.R.I.C., A.C.P., F.G.S., and Mr. Percy Evans, M.A., F.G.S.

Custodian: The Royal Bank of Scotland, Western Branch.

FOULERTON AWARD

The Foulerton Award and Certificate for the year was given to Mr. D. F. W. Baden-Powell, M.A., B.SC., F.G.S., in recognition of his services to Geology and the Association.

Certificates were also issued retrospectively to twenty-seven former recipients of the award. Thanks are due to Mrs. A. J. Butler for inscribing these certificates.

HOUSE LIST

Mr. T. Eastwood retires as Senior Vice-President and Messrs. W. E. Smith, D. Curry and S. Bracewell as ordinary members of the Council.

Dr. G. Himus, who was President 1952–4 and Secretary for Field Meetings 1943–8, resigns as Vice-President at his own request.

Thanks are due to these members for services rendered to the Association.

DELEGATES

The official delegates of the Association at the XXth Session of the International Geological Congress in Mexico, 1956, were Mrs. Eyles, Mrs. Harrison and Professor and Mrs. Hollingworth.

Dr. R. G. Abercrombie, Mr. A. Ludford, Mr. J. Ranson and Mr. J. T. Wattison were representatives of the Association for the British Association Meeting in Sheffield.

REPORT OF THE SESSION 1956

Ordinary Meeting, 6 *January* 1956. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

Richard Burns, William G. E. Caldwell, B.SC., Robert Marx Dreyer, B.S., M.S., Ph.D., Alan Russell Facey, Brian George Gardiner, B.SC., F.R.E.S., Harold Graham Gear, E. A. Hassan, Jnr., Michael Darby Hindley, Frank Benjamin George Norris, Gerald David Roberts, Eyland Augustus Washington and Valerie Williams were elected members of the Association.

The following paper was read: 'The Namurian Usk Anticline', by Professor T. Neville George, D.SC., F.G.S.

Ordinary Meeting, 3 *February* 1956. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

Peter Harding Bromley, M.SC., Mrs. Carol Brown, J. A. Coope, Adrian Vernon Brough Gibson, John McAllister Hart, John Howell, James Frederick Jackson, F.G.S., Richard Alan Llewellyn, Wilfred Alfred Motta, Peter John Smart, Norman Soul, B.A., M.SC., and Samuel Philip Ward Street, F.R.C.S., F.I.C.S., were elected members of the Association.

Messrs. W. S. Pitcher and I. T. Pritchard were elected Auditors of the Association.

The following paper was read: 'The Co-relation of the Pliocene and Pleistocene Marine Beds of Britain and the Mediterranean', by D. F. W. Baden-Powell, M.A., B.SC., F.G.S.

Annual General Meeting, 2 *March* 1956. L. R. Cox, M.A., SC.D., F.R.S., F.G.S., President, in the chair.

The Annual Report of the Council (already circulated) was taken as read. It was moved by Mr. J. M. Hancock and seconded by Mr. A. J. Lloyd, 'That the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for 1956'. Mr. E. E. S. Brown proposed and Mr. A. G. Bell seconded that the following words be added to the Resolution, 'but that this meeting deplores the delay to the issue of the PROCEEDINGS'. The amendment was carried.

The President declared the following members duly elected as Officers and Members of the Council in accordance with Rule XIII: *President*, C. W. Wright, M.A., F.G.S.; *Vice-Presidents*, T. Eastwood, A.R.C.S., M.I.M.M., F.G.S., H. Dighton Thomas, M.A., Ph.D., F.G.S., G. W. Himus, Ph.D., F.G.S., A. G. Davis, F.G.S., L. R. Cox, M.A., SC.D., F.R.S., F.G.S.; *Treasurer*, L. J. Pitt, F.G.S.; *Secretaries*, General—F. H. Moore, B.SC., Ph.D., F.G.S.; Field Meetings—S. W. Hester, F.G.S.; Publications Committee—M. K. Wells, M.SC., Ph.D.; *Editor*, A. J. Dollar, B.SC., Ph.D., A.K.C., F.R.S.E., F.G.S.; *Librarian*, R. Bradshaw, M.SC., F.G.S.; *Twelve other Members of Council*, W. E. Smith, M.SC., F.G.S., D. Curry, M.A., F.G.S., S. Bracewell, B.SC., D.I.C., A.R.C.S., F.G.S., Gilbert Wilson, Ph.D., M.SC., D.I.C., F.G.S., Mrs. E. M. Evans, M.SC., F.G.S., Mrs. J. V. Harrison, M.A., B.SC., D. V. Ager, B.SC., Ph.D., D.I.C., F.G.S., S. E. Hollingworth, M.A., D.SC., F.G.S., J. F. Hayward, M.SC., Ph.D., F.G.S., H. M. Montford, O.B.E., B.SC., Isles Strachan, B.SC., Ph.D., F.G.S., D. F. W. Baden-Powell, M.A., B.SC., F.G.S.

It was moved by Mr. W. H. Steele, seconded by Mrs. E. W. Hart, and duly carried, 'That the best thanks of the Association be given to the retiring President, the Officers, retiring members of Council and the Auditors'.

Mr. J. M. Hancock paid tribute to the services of Mr. R. Reeley, who was General Secretary to the Association from 1945–55.

The Foulerton Award and Certificate were presented to Mr. D. F. W. Baden-Powell, M.A., B.SC., F.G.S., in recognition of Services rendered to Geology. The President said:

> Mr. Baden-Powell: Past recipients of the Foulerton Award have included several members of the Association who, in a non-professional capacity, have carried out extremely valuable work in the field of Pleistocene geology and palaeontology. The Council of the Association, in deciding to make the award to you at the present time, feel that you are worthily maintaining the tradition of research in this field, as a special activity of members.
>
> One important aspect of your work has been the investigation of raised beaches and other marine deposits of relatively late geological age, with particular reference to the remains of mollusca and other organisms found in them. You have shown that such fossils can assist in correlation in two different ways: first, they sometimes show evolutionary changes of direct chronological value; and secondly, since the past distribution of species still living has been affected by climatic fluctuations which were widespread, the assemblages which occur may throw indirect light on geological age. In a series of able papers on these deposits you have discussed the evolution of the Chesil Bank, the marine March Gravels, the Glacial and Interglacial marine beds of Northern Lewis, the Holderness deposits, and the Corton Beds.
>
> You have also studied boulder clays and their erratics, and have discussed the vexed questions of their correlation and of the multiplicity or otherwise of Pleistocene Ice Ages. I may allude especially to your valuable paper, published in 1948, on the Chalky Boulder Clays of Norfolk and Suffolk, in which you recognised two distinct Boulder Clays and assigned to them names (the Gipping and Lowestoft Boulder Clays) which have already become established in geological terminology. Your field of research is a notoriously controversial one in which the unfortunate results of disagreement between some of your predecessors have stopped little short of homicide. In your case, however, I think that I may truthfully say that you have many friends and no enemies.
>
> Your investigations have not been confined to this country, for in Italy and elsewhere you have studied the succession of Pliocene and Pleistocene deposits and, by careful attention to palaeontological and other evidence, have established their correlation with those in Great Britain. The Association is grateful to you for your leadership of some very successful Field Meetings, pleasant memories of which are retained by those who attended them. As one who has known you for some thirty years I am particularly happy to have the pleasant duty of handing to you this year's Foulerton Award.

The President then delivered his address entitled, 'The Clams as Food for Thought'.

It was moved by Mr. F. A. Bowater, seconded by Mrs. C. B. Welch, and duly carried, 'That the best thanks of the Association be accorded the President for his Address'.

Ordinary Meeting, 2 *March* 1956. C. W. Wright, M.A., F.G.S., President, in the chair.

Bernard Robert Brown, James Fitz-Hubert Brown, Reginald Jack Chapman, Richard Wendell Channon, N.D.A., N.D.D., Basil Vincent Davis, John Christopher Doyle, Edward Maurice Finch, Jeffrey Fletcher, L.D.S., R.C.S., Eng., John David Russell Fryer, Lee Gore, George William Patrick Jarvis, B.A., Clive Roderick Jones, B.SC., F.G.S., David Gwyn Jones, M.SC., John Beverly Little, Derek Hylton Maling, B.A., F.R.G.S., F.R.Met.SOC., Marjorie Mather, B.A., William Haydn Middleton, B.SC., John William Murray, Lucy Anne Parnell, John Horace Parry, M.B.E., Ph.D., Manuel A. Rivera, Howard William Schwartz, B.SC., Jack Shirley, D.SC., F.G.S., Ivy Phillis Steele, John Michael Thomas, Lancelot Churchill Adalbert Thompson, B.SC., Ph.D. and William Addison Willox, B.SC. were elected members of the Association.

Ordinary Meeting, 6 *April* 1956. C. W. Wright, M.A., F.G.S., President, in the chair.

Frederick William Charles Baker, A.R.C.A., Peter George Fookes, George James Ford, Joan Winniefred Gaynair, Antony Collen Gifford, Peter Roy Hartley, Nevile Hood-Daniel, John Douglas Hudson, Arthur Raymond Loveless, M.A., Ph.D., John Stanley Nathan, Sidney Alfred Nicholas, David Henry Parker and Dorothy Ceciline Scott were elected members of the Association.

The following paper was read: 'Certain Abandoned Channels of Pleistocene and Holocene Age in the Lea Valley, and their Deposits', by John F. Hayward, Ph.D., M.SC., F.G.S.

Ordinary Meeting, 4 *May* 1956. H. Dighton Thomas, M.A., Ph.D., F.G.S., Vice-President, in the chair.

Iris Dickinson, Alan Downes, B.SC., Clifford Embleton, M.A., Ph.D., Thomas Lionel Gracey, M.B., B.Ch., B.A.O., D.P.H., Bryan Jesse Hockridge, Arthur Keith Hoskins, David Leonard Jones, B.SC., F.R.G.S., Albert George Kenny, Edward Lionel Martin, John Henry Palmer, B.SC., Ph.D., Professor Doktor phil. nat. Gerhard Solle, Robin Witterick Spon-Smith, Teresa Sonia Willan and Anthony Young, B.A. were elected members of the Association.

The following papers were read: (a) 'The Occurrence of Micaceous Haematite in the Hennock–Lustleigh Area, Eastern Dartmoor'; (b) 'An Aero-Magnetic Survey of the Church Stretton Area, Shropshire', by Frederick A. Henson, B.SC., Ph.D., F.G.S.

Ordinary Meeting, 1 *June* 1956. C. W. Wright, M.A., F.G.S., President, in the chair.

Richard Keith Banfield, James Howard Bateson, Mrs. Doris Greville Butcher, John Donald Curphey, M. Symes and Lindo Augustus Wong, B.A. were elected members of the Association.

The following paper was read: 'The Terraces of the Middle Thames', by K. R. Sealy, M.SC., F.G.S., & Catherine E. Sealy, M.A.

Ordinary Meeting, 6 *July* 1956. C. W. Wright, M.A., F.G.S., President, in the chair.

Ansel Charles Dunham, Alexander Macintosh Honeyman, M.A., B.SC., F.G.S., Archibald Leonard Lee, Peter John Lefroy-Owen, Albert John Rowell, B.SC., Ph.D., F.G.S. and Hugh Simon Torrens were elected members of the Association.

The following papers were taken as read: (a) 'The Minor Intrusive Suite associated with the Criffell–Dalbeattie Granodiorite Complex', by W. J. Phillips, and (b) 'Some new Liassic Terebratuloids', by D. V. Ager, B.SC., Ph.D., D.I.C., F.G.S.

A lecture was given on 'The Geology of Turkey, with special reference to its Building-Stones', by K. Erguvanli, D.SC., F.G.S.

Ordinary Meeting, 3 *November* 1956. C. W. Wright, M.A., F.G.S., President, in the chair.

James Gordon Avery, Bernice Godsmark, B.SC., Henry Hepworth Hargrave, Gilroy Henderson, B.SC., Vivian Jenkins, Barry Adrian Jones, Glenn Carleton Prescott, Jr., A.B., M.S., M.P.A., Dorian Glen Whitney-Smith, David Wolfe and James Barron Wright were elected members of the Association.

The Reunion which followed was held at the Chelsea Polytechnic and was attended by about 350 members and friends. (For list of exhibits, see page 83.)

Ordinary Meeting, 7 *December* 1956. C. W. Wright, M.A., F.G.S., President, in the chair.

Vernon Lloyd Aquart, Russell Scott Arthurton, Peter Frederick Ballance, David Henry Barrett, John Brandon, A.M.I.E.T., Herbert Reginald Bramwell, Anthony Peter Collard, Maurice Broadhurst Clark, Professor Dr. Ernst Cloos, Sydney Colley, Graham Evans, B.SC., Eugene Alfonso Ffolkes, B.SC., M.SC., A.M.AS.A.E., Ian Hubert Ford, B.SC., John Philip Ford, Edward David Hoskin Freeman, David Godfrey Gee, Anthony Michael Glazer, George Cavell Graver, A.R.I.C., Francis Clayton Green, Frederick James Winsor Holwill, Peter Jones, Erik N. Kjellesvig-Waering, B.S., Brian Anthony Lavers, B.SC., A.R.S.M., Garibaldi M. Lawson, Michael John Leeds, Nydia Luthy, B.S., M.A., Ph.D., Thomas Arthur Moore, Arthur Y. Mullikin, Alison Enid Rennie, B.A., John William Rowling, Rosemary Samways, John Francis Savage, B.SC., F.G.S., Brian Sipson, Norman

Rodney Smith, John Howard Stuart Smith, Rev. Noel Francis Tripp, M.C., T.D., M.A., Peter Thomas Walsh, James Wheildon, Barbara Charlotte Hambleton Wilde, B.A., Dip. Ed. and Graham Lee Williams were elected members of the Association.

The following paper was read: 'The Cenomanian Limestone of the Beer District, South Devon', by W. E. Smith, M.SC., F.G.S.

LIST OF EXHIBITS

British Museum (Natural History), Department of Palaeontology

(*a*) *Rhinoceras* from Selsey.
(*b*) Insects, etc., from the Lias of Charmouth, Dorset.
(*c*) The Caradoc Fauna of the Cross Fell Inlier.

Directorate of Colonial Geological Surveys, Photo-geological Department

A demonstration by 3-D projection of Geological Features from vertical aerial photographs. R. L. Birch.

Geological Survey and Museum

(*a*) Specimens with explanatory diagrams from Geological Survey boreholes at Highoredish and Fallgate, Derbyshire.
(*b*) New Geological Survey maps.

Ministry of Housing and Local Government

Economic Geology in the Service of Town and Country Planning. R. O. Warburg.

Ager, Dr. D. V.

Specimens collected by a student mapping party in the French Juras, July–August 1956.

Barron, R. S. (Dauntsey's School)

River Gravel Deposits of the River Avon, north of Chippenham, Wilts.

Bassett, Dr. Henry

Minerals collected in East and Central Africa during 1950 to 1954.

Bottley, Mr. and Mrs. E. P.

(*a*) Cobalt-Calcite and other fine Spanish minerals.
(*b*) A new find of Ruby Corundum in Norway.
(*c*) Fine American Minerals.
(*d*) New cast of Olenellus.
(*e*) A Collection of Rocks arranged for teaching Metamorphism.

Carreck, J. N. and M. W.

(*a*) Non-marine mollusca determined by A. G. Davis, and other material, from the Pleistocene and Holocene of the Somme Valley and the Pas de Calais, 1956.
(*b*) Remains of Neolithic and Iron Age birds, rodents and amphibians from Maiden Castle, Dorset.

Carreck, M. W.
The Association's albums of photographs, mainly prepared by the late Miss M. S. Johnston, with some recent additions.

Collins, J.
A selection of Decapod and Cirripede Crustacea. A series of specimens representing species added to the collection since November 1955.

Curry, D.
Fossils from a new exposure of London Clay at Nursling, near Southampton.

Cutrock Engineering Co. Ltd.
(*a*) Lapping, Cutting, Grinding, Splitting and Crushing Machines.
(*b*) Hotplates.
(*c*) Stereometers, Clinometers, Micrometers and Goniometers.
(*d*) Range of Hammers.

Dollar, Dr. A. J.
(*a*) Two uncommon igneous rocks.
(*b*) Geological nomograms.

Eccleston, B. L.
Ludlovian Conodonts.

Gunner, A.
Cornish Mineral Rocks for Identification.

Hallimond, Dr. A. F.
Point Counter and Microscope Stage, designed by I. H. Ford (University of Bristol).

Hallimond, Dr. A. F.
A Colour Film: *The Polarising Microscope.*

Hancock, M.
Cretaceous Rocks from Western Scotland.

Hayward, Dr. John F.
(*a*) Material from the raised beach of Start Bay, South Devon.
(*b*) Molluscs from the *Patella* Beach of Gower, Glamorgan.

House, M. R.
Some recently collected Devonian Goniatites from Devon, Cornwall, France and Germany.

Jamaica Group. L. J. Chubb
Photographs taken at Field Meetings.

Jones, Dr. Francis and D. J. Shearman
Photographs of Kilimanjaro.

Jones, Dr. Francis
(*a*) Kodachromes of Rhodesia mainly from Kariba.
(*b*) Rock specimens from Kariba neighbourhood and Rock Sections.

Jones, R. J.
Very Low Altitude Air Photography.

Lowe, M. J. (Trench Secondary School for Boys)
Lino cuts using fossils as a motif.

Milbourne, R. A. and R. Casey
The Ammonite Fauna of the Gault at Ford Place, Wrotham, Kent.

Potter, John F.
Silurian–Devonian Lithologies in the Llandeilo District.

Ross, F. Stenhouse
Specimens of ammonites (Jurassic and Lias) and echinoids (Upper Chalk) collected during Field Meeting at Pewsey Vale and Devizes, 31 August to 2 September.

Samson, J. G.
Walker's Geological Map of 'England, Wales and part of Scotland' dated 31 March 1837, in colour.

Stinton, Fred C.
Characteristic Fossils of the Barton Beds.

Trechmann, Dr. C. T.
(*a*) A series of rocks from Jamaica to show the passage of Eocene conglomerates of the Carbonaceous Shale Series Formation into Schist, Crystal Tuff, Andesite, black Pitchstone, Petrosilex, Steatite, and Serpentine in different parts of the Island.
(*b*) A series from the Northern Range of Trinidad to show the metamorphic front.

Venables, Edmond M.
Micro-coleoptera of the London Clay.

Walker, G. P. L.
Volcanic rocks and minerals from Iceland.

Warburg, R. O.
Colour transparencies of Quarries in the London Area.

Whitten, D., G. T. Raine and Students of the Geology Section, Kingston Technical College
Field work as the basis for teaching Geology.

Wilson, Dr. Gilbert
(*a*) A specimen illustrating the development of a drag-fold.
(*b*) Specimens of pebbles from the Torridonian Conglomerate at Badralloch, near Ullapool, Wester Ross.
(*c*) Specimens of folded lineations and other structures from the Department of Geology, Imperial College.
(*d*) Colour transparencies of Highland Scenery.

Wright, C. W.
British Cretaceous Pseudo-ceratites. Some New Acquisitions.

FIELD MEETINGS 1956

The following Field Meetings and demonstrations took place:

13 *January*. Visit to the Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce, Hatton Garden, at the invitation of B. W. Anderson.

11 *February*. Visit to the Department of Geology and Mineralogy, Oxford University, at the invitation of Professor L. R. Wager, M.A., SC.D., F.G.S., and Dr. L. H. Ahrens.

17 *March*. Visit to the Zoological Gardens, Regent's Park, to study living representatives of Pleistocene Mammals. Director, J. N. Carreck.

29 *March*–6 *April*. Easter Field Meeting in Jersey. Directors, Dr. F. A. Henson, B.SC., Ph.D., F.G.S., F.R.Met.S. and Dr. A. K. Wells, D.SC., F.G.S., assisted by Dr. A. C. Bishop, B.SC., Ph.D., and Miss Casimir, F.G.S.

21 *April*. Visit to the National Physical Laboratory, Teddington, under the guidance of R. H. P. Spencer.

28–9 *April*. Week-end Field Meeting at Alum Bay and Colwell Bay, Isle of Wight. Director, D. Curry, M.A., F.G.S.

5 *May*. Field Meeting to Study the Stratigraphy, Structure and Geomorphology of south-west Surrey. Director, Dr. T. Barnard, B.SC., Ph.D., D.I.C., F.G.S.

19–22 *May*. Whitsun Field Meeting in the Gloucester–Ledbury–Malvern Region. Directors, D. G. A. Whitten, B.SC., A.R.C.S., F.G.S., and G. T. Raine, B.SC., F.G.S.

2 *June*. Visit to Kew Gardens to examine living representatives of Fossil Plants. Director, Dr. D. V. Ager, B.SC., Ph.D., D.I.C., F.G.S.

17 *June*. Field Meeting in the Chiltern Hills to study problems of Stratigraphy and Geomorphology. Directors, A. J. Thomasson and B. Avery.

6–8 *July*. Week-end Field Meeting at Thaxted, Essex. Director, Dr. J. F. Hayward, M.SC., Ph.D., F.G.S.

21 *July*. Field Meeting at Hastings and Fairlight. Director, N. F. Hughes, M.A.

28 *July*. Field Meeting at Harefield, Middlesex. Director, S. W. Hester, F.G.S.

26 *August*. Field Meeting at Ford Place, Wrotham, Kent. Director, R. A. Milbourne.

31 *August*–2 *September*. Week-end Field Meeting at Pewsey Vale and Devizes, Wiltshire. Director, R. S. Barron.

8–18 *September*. Summer Field Meeting in South Wales. Directors, Dr Gwyn Thomas, B.SC., Ph.D., D.I.C., F.G.S., D. G. Jones, T. R. Owen, M.SC., A.R.I.C., A.M.I.Chem.E., F.G.S., J. H. Price and W. D. Ware.

23 *September*. Field Meeting at Calvert and Woodham, Buckinghamshire. Director, Dr. J. H. Callomon.

29 *September*. Field Meeting at Dartford Heath, Kent. Director, J. N. Carreck.

17 *November*. Demonstration of the Stones of Westminster Cathedral. Directors, Canon Bartlett and R. E. Butler, F.G.S.

8 *December*. Visit to the Geology Department, Queen Mary College, London, at the invitation of Dr. J. F. Kirkaldy, D.SC., F.G.S.

NORTH-EAST LANCASHIRE GROUP

The following meetings and Field Meetings were held:

20 *January*. Lecture: 'Settlement on the Illawarra Coalfield', by M. Powell, B.A., F.R.G.S.

3 *February*. Lecture: 'Under the Hills', by R. Morris.

9 *March*. Chairman's Address: 'The Glacial Geology of East Lancashire', by J. Ranson, A.M.I.Min.E., F.G.S.

28 *April*. Field Meeting: 'The Lower Carboniferous Succession of Clitheroe and Pendle Hill.' Director, S. Westhead.

26 *May*. Field Meeting: 'The Horwich Area.' Director, D. H. Learoyd, B.SC., F.G.S.

16 *June*. Field Meeting: 'The Glacial Features of the Rossendale and Whitworth Valleys.' Director, J. Ranson, A.M.I.Min.E., F.G.S.

1 *July*. Field Meeting: 'Ingleborough. The Carboniferous Limestone and Underground Waters.' Director, N. Thompson.

8 *September*. Field Meeting: 'The Millstone Grit Succession, Tectonics and Glacial Features of the Cliviger Valley and Green's Clough.' Director, I. A. Williamson, F.G.S.

19 *October*. The thirty-third Annual General Meeting. Résumés of the Field Meetings were given by the various directors.

10 *November*. Field Meeting: 'Open-cast Coal Workings and Glacial Geology of Padiham District, near Burnley.' Director, G. T. Roberts, B.SC., F.G.S.

16 *November*. Lecture: 'The Geology of Clitheroe and Pendle Hill', by S. Westhead.

1 *December*. Field Meetings: In the morning, 'The Oil Boring at Crawford near Upholland'. Director, A. P. Terris, B.SC., D.I.C., F.G.S. (by kind permission of the British Petroleum Co., Ltd.). In the afternoon, 'The Permian Succession in Skillaw Clough'. Directors: G. Brown, B.SC., F.G.S., and D. H. Learoyd, B.SC., F.G.S.

7 *December*. Lecture: 'The Coal Measures of the Burnley Area', by G. T. Roberts, B.SC., F.G.S.

MIDLAND GROUP

The following meetings and Field Meetings were held:

28 *January*. Films lent by Petroleum Films Bureau: *The Changing Earth, Down a Long Way* and *Assam Oil Survey*.

25 *February*. Conversazione.

5 *May*. Field Meeting: 'Kirtlington and Banbury.' Director, I. Strachan, B.SC., Ph.D., F.G.S.

2 *June*. Field Meeting: 'Hartshill.' Director, I. Strachan, B.SC., Ph.D., F.G.S.

24 *June*. Field Meeting: 'Coventry–Rugby area.' Director, Professor Shotton, M.B.E., M.A., SC.D., F.G.S.

8 *September*. Field Meeting: 'Lickey–Bromsgrove area.' Director, P. A. Garrett.

13 *October*. Lecture: 'The Carboniferous Limestone of the Staffs–Derbyshire Border', by A. Ludford, M.SC., F.G.S.

10 *November*. Lecture: 'Evolution and Classification of Starfish', by C. W. Wright, M.A., F.G.S.

8 *December*. Exhibition of Coloured Slides.

NORTH STAFFORDSHIRE GROUP

The following meetings and Field Meetings were held:

12 *January*. Lecture: 'The Geology of Shropshire', by W. T. Dean, Ph.D., B.SC., F.G.S.

9 *February*. Members' Slides and Photographs.

15 *March*. The Annual General Meeting: Lecture, 'The Geology of Portugal', by the Chairman, J. T. Wattison, F.G.S., F.R.E.S.

12 *April*. Lecture: 'The St. Austell Granite', by C. S. Exley, M.A., D.Phil., F.G.S.

22 *April*. Field Meeting: 'The Carboniferous Limestone of Llanymynech', directed by J. T. Wattison, F.G.S., F.R.E.S.

5 *May*. Field Meeting (Research Group): The Astbury Inlier of Carboniferous Limestones', directed by Professor F. Wolverson Cope, D.SC., F.G.S.

10 *May*. Lecture: 'Quaternary Glaciations in Britain', by G. T. Warwick, M.B.E., F.G.S.

21–3 *May*. Whitsun Field Meeting: 'The Oxford District', directed by J. C. Parrack, B.SC., F.R.G.S.

27 *May*. Field Meeting: 'The Lias of the Cheltenham area', directed by D. O. Thomas, F.G.S.

17 *June*. Field Meeting: 'Wroxton Ironstone Workings', directed by J. Myers, B.SC., F.R.G.S., F.G.S.

7 *July*. Field Meeting (Research Group): 'The Dane Valley', directed by J. C. Parrack, B.SC., F.R.G.S.

11 *October*. The Annual Conversazione.

8 *November*. Lecture: 'Fossils in the Field', by P. H. Shelford, B.SC., F.G.S.

13 *December*. Members' Slides and Photographs.

JAMAICA GROUP

The following meetings and Field Meetings were held:

29 *January*. Field Meeting: 'Port Esquivel and the offshore islands.' Director, Prof. V. A. Zans, F.G.S.

4 *March*. Field Meeting: 'A repeat trip to Port Esquivel and the offshore islands.' Director, L. J. Chubb, Ph.D., M.SC., F.G.S.

23 *March*. Lecture: 'The development of the water resources of the Clarendon Plains', by S. A. G. Taylor.

25 *March*. Field Meeting: 'The Mid-Clarendon Irrigation Scheme.' Director, S. A. G. Taylor.

27 *May*. Field Meeting: 'The Portland Ridge Caves.' Director, C. B. Lewis, B.A.

27 *July*. Film Show: Two films, *Alumina Jamaica* and *The Kitimat Story*, introduced by S. M. Patterson.

29 *July*. Field Meeting: 'The Limestone Quarries, Bauxite Mines and Kirkvine Works of Alumina Jamaica Limited.' Director, D. A. Bryn Davies, Ph.D., B.SC.

16 *August*. Lecture: 'A comparison between British and Jamaican limestone scenery', by Prof. H. C. Versey.

25 *November*. Field Meeting: 'The Benbow Inlier and Guys Hill District.' Directors, L. J. Chubb, Ph.D., M.SC., F.G.S., and B. V. Bailey.

7 *December*. Annual General Meeting and Dinner.

DONATIONS TO THE LIBRARY

ALLEN, P. 1955. Age of the Wealden in North-western Europe. *Geol. Mag.*, **92**, 265–81.

BIRCH, F. 1954. The present state of geothermal investigations. *Geophysics*, **19**, No. 4, 645–59.

———. 1954. The earth's mantle: elasticity and constitution. With further discussion by author. *Trans. Amer. geophys. Un.*, **35**, 79–85.

———. 1955. Physics of the crust. The crust of the earth. *Spec. Pap. geol. Soc. Amer.*, **62**, 101–18.

BISSET, C. B. 1955. Minerals and industry in Tanganyika. *Colon. Geol. min. Resour.*, **5**, No. 1, 40–50.

COLLINS, B. W. 1954. Fluctuations of ground-water levels in New Zealand and their significance. *Association Internationale d'Hydrologie, Assemblée générale de Rome*, tom. 2, pp. 25–31.

————. 1954. The occurrence and utilisation of ground-water in New Zealand. *Association Internationale d'Hydrologie, Assemblée générale de Rome*, tom. 2, pp. 295–307.

————. 1956. Underground water supplies for irrigation. *Proc. Lincoln College Farmers' Conference*, 1956, pp. 70–85.

CONGO BELGE. *Service Géologique*. Promenade géologique à Léopoldville. Léopoldville. 1954.

COOMBS, D. S. 1955. X-ray observations on wairakite and non-cubic analcime. *Min. Mag.*, **30**, No. 230, 699–708.

COOPE, G. R. 1956. The insertion of Septa in the later growth stages of clisiophyllid corals. *Geol. Mag.*, **93**, No. 3, 233–41.

COUPER, R. A. 1954. Lower Pleistocene plant microfossils from the Glenhope beds and Mouture gravels, Nelson, New Zealand. *N.Z. J. Sci. Tech.*, B, **36**, No. 2, 136–9.

DAVIES, K. A. 1956. The geology of part of South-east Uganda. Entebbe. *Geological Survey of Uganda memoir No. 8.*

DIBBLE, R. R. 1956. Gravity survey for possible oil structures, Kotuku-Ahaura district, North Westland. *N.Z. J. Sci. Tech.*, B, **37**, No. 5, 571–86.

DINES, H. G. 1956. The metalliferous mining region of South-west England. London. *Mem. geol. Surv. U.K.*

DUNNINGTON, H. V. 1955. Close zonation of Upper Cretaceous globigerinal sediments by abundance ratios of Globotrincana species groups. *Micropaleontology*, **1**, No. 3, 207–91.

EGOROFF, A. 1955. Esquisse géologique provisoire du sous-sol de Léopoldville. *Congo Belge, Service Géologique, Carte géologique de Léopoldville*, pp. 1–15.

———— & J. SNEL. 1955. Observations géologiques le long de la ligne du chemin de fer, entre Léopoldville et Matadi. [Léopoldville.]

FAWLEY, A. P. & T. C. JAMES. 1955. A pyrochlore (Columbium) carbonatite, Southern Tanganyika. *Econ. Geol.*, **50**, 571–85.

FLEMING, C. A. 1955. Castlecliffian fossils from Ohope Beach, Whakatane. *N.Z. J. Sci. Tech.*, B, **36**, No. 5, 511–22.

————. 1955. Kapitean (Upper Miocene) mollusca from Te Waewae Bay, Southland, N. Zealand. *Trans. roy. Soc. N.Z.*, **82**, pt. 5, 1049–59.

————. 1953. Quaternary geochronology in New Zealand. *Actes du IV Congrès Internationale du Quaternaire, 1953*, pp. 1–8.

————. 1955. A new subspecies of scallop from Byron Bay, N.S. Wales. *Aust. Zool.*, **12**, pt. 2, 108–9.

GRANGE, L. I. 1955. Geothermal steam for power in N. Zealand. *Bull. N.Z. Dep. sci. industr. Res.*, 117.

GREAT BRITAIN. *Geological Survey.* Maps, new series, 1 inch.
Sheet 8. Elsdon. Solid, drift. 3rd ed., 1951.
Sheet 14. Morpeth. Solid. 3rd ed., 1951. Drift. 3rd ed., 1955.
Sheet 15. Tynemouth. Solid, drift. 3rd ed., 1953.
Sheet 140. Burton upon Trent. Solid and drift. 6th ed., 1953.
Sheet 171. Kettering. Drift. 6th ed., 1951.
Sheet 273. Faversham. Solid and drift. 6th ed., 1953.
Sheet 342. Weymouth. Drift. 3rd ed., 1949.

GREGG, D. R. 1956. Eruption of Ngauruhoe, 1954–5. *N.Z. J. Sci. Tech.*, B, **37,** No. 6, 675–88.

GUPPY, E. M. 1956. Chemical analysis of igneous rocks, metamorphic rocks and minerals, 1931–54. London. *Mem. geol. Surv. U.K.*

HAMPTON, J. S. 1955. Report on temporary geological exposure. *Lond. Nat.*, 1955, 77–8.

————. 1955. Additions to the chalk rock fauna of Westerham, Kent. *Lond. Nat.*, 1955, 80–2.

————. 1955. A roadside section in the upper chalk near Downe, Kent. *Lond. Nat.*, 1955, 78–80.

HARDIE, W. G. 1955. The problem of facies changes and sliding, south of Loch Leven, Argyllshire. *Geol. Mag.*, **92,** No. 6, 506–11.

HARRINGTON, H. J. 1955. The geology of Naseby district, Central Otago. *N.Z. J. Sci. Tech.*, B, **36,** No. 6, 581–99.

HAYASE, I. 1955. The radioactivity of rocks and minerals studied with nuclear emulsion. III. Radioactivity of biotite of the Tanakamiyama granite, Shiga Pref., Japan. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 177–84.

HODSON, F. 1956. Carboniferous goniatites from Blacklion, Co. Leitrim, Ireland. *Geol. Mag.*, **92,** No. 1, 41–2.

HUGHES, H. 1955. The pressure effect on the electrical conductivity of peridot. *J. geophys. Res.*, **60,** No. 2, 187–91.

ITOIGAWA, J. 1955. Molluscan fauna of the Mizunami group in the Iwamura Basin. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 127–43.

KAPLIN, I. R. 1956. Evidence of microbiological activity in some of the geothermal regions of New Zealand. *N.Z. J. Sci. Tech.*, B, **37,** No. 6, 639–62.

KEAR, D. 1955. Mesozoic and Lower Tertiary stratigraphy and limestone deposits, Torehina, Coromandel. *N.Z. J. Sci. Tech.*, B, **37,** No. 2, 108–14.

KUMAGAI, N. & I. HIDEBUMI. 1955. Measurement of thermal conductivity of granites at high temperatures from 100°C. to 690°C. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 263–80.

Lawson, J. D. 1956. The Ludlovian rocks of the Welsh Borderland. *Advanc. Sci.*, **12,** No. 49, 563–70.

Macdonald, G. J. F. 1955. Gibbs free energy of water at elevated temperatures and pressures with application to the brucite-periclase equilibrium. *J. Geol.*, **63,** No. 3, 244–52.

McKellar, I. C. 1955. Stranded moraines of the Hooker and Mueller glaciers. *N.Z. J. Sci. Tech.*, B, **37,** No. 2, 221–3.

Mason, B. 1955. Notes on some New Zealand minerals. *N.Z. J. Sci. Tech.*, B, **36,** No. 6, 557–60.

Mineralogisch-geologische Wissenschaften: sciences minéralogiques et géologiques. *Bibliographia scientiae naturalis helvetica*, **30,** 1954, 220–7.

Moore, R. C. *Ed.* 1955, 1956. Treatise on invertebrate paleontology. New York. Part F, Coelenterata. Part P, Arthropoda, 2: Chelicerata, *etc.* Part V, Graptolithina.

Morishima, M. 1955. Deposits of foraminiferal tests in the Tokyo Bay, Japan. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 213–22.

Morishita, A. 1955. Notes on Echinarachnius in Japan. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 223–36.

Nakazawa, K. 1955. A study on the Pelecypod-fauna of the Upper Triassic Nabae group in the northern part of Kyoto Prefecture, Japan. Part 3: Halobiids and others. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 243–60.

New Zealand. *Geological Survey.* 1955. Abstracts of papers on New Zealand geology published during 1954. *N.Z. J. Sci. Tech.*, B, **37,** No. 3, 416–35.

Nigeria. *Geological Survey.* Geological map of Nigeria, 1:2,000,000. 1954.

Polskie Towarzystwo Geologiczne. 1956. *Regionalna geologia Polski*, tom 2. Region Lubelski. Kraków.

Powell, A. W. B. 1955. Mollusca of Southern Island of New Zealand. Wellington. *Cape Expedition series, No. 15.*

Powell, D. W. 1956. Gravity and magnetic anomalies in North Wales. *Quart. J. geol. Soc. Lond.*, **91,** 375–97.

Pulfrey, W. 1955. A structural map of the basement system, Kenya. *Association des Services géologiques africains, Compte rendu et communications*, 1954, pp. 219–20.

Raw, F. 1955. The Malacostraca, their origin, relationships and phylogeny. *Ann. Mag. nat. Hist.*, ser. 12, **8,** 731–56.

Reed, J. J. & A. E. Leopard. 1954. Sediments of Cook Strait. *N.Z. J. Sci. Tech.*, B, **36,** No. 1, 14–24.

Robertson, E. C. 1955. Experimental study of the strength of rocks. *Bull. geol. Soc. Amer.*, **66,** 1275–314.

Rose, G. N. & P. E. Kent. 1955. A Lingula-bed in the Keuper of Nottinghamshire. *Geol. Mag.*, **92,** No. 6, 476–80.

SAWAI, K. 1955. Preliminary report on deposits of foraminiferal tests in Seto-Naikai, Japan (Hiuchi-Nada). *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 261–2.

SCHOFIELD, J. C. 1956. Methods of distinguishing sea-ground-water from hydrothermal water. *N.Z. J. Sci. Tech.*, B, **37,** No. 5, 597–602.

SHOTTON, F. W. 1956. Some aspects of the new Red Desert in Britain. *Liverpool & Manchester Geol. J.*, **1,** pt. 5, 450–65.

STEINER, A. 1955. Wairakite, the calcium analogue of analcime, a new zeolite mineral. *Min. Mag.*, **30,** No. 230, 691–8.

SUDAN. *Geological Survey*. Report, 1953–5. Khartoum, 1955.

SUGGATE, R. P. 1955. Deep drilling for coal—Brunner-Mount Davy block, Greymouth coalfield, New Zealand. *N.Z. J. Sci. Tech.*, B, **37,** No. 1, 86–105.

———. 1956. Puponga coalfield. *N.Z. J. Sci. Tech.*, B, **37,** No. 5, 539–59.

TANGANYIKA. *Geological Survey*. Maps, 1:125,000.
Degree sheet 53. Mpwapwa, SW. quarter. 1955.
Degree sheet 64. Uluguru, SE. quarter. 1955.
Degree sheet 64. Uluguru, SW. quarter. 1956.
Degree sheet 74. Madaba, NE. quarter. 1955.
Degree sheet 74. Madaba, SW. quarter. 1955.

TATEKAWA, M. 1955. The pegmatites of the Oku-Tango district of Kyoto Prefecture researched chiefly from the viewpoint of trace elements. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 199–212.

UEDA, T. 1955. The crystal structure of allanite, $OH(Ca, Ce)_2 (Fe^{III}, Fe^{II}) Al_2OSi_2O_7SiO_4$. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 145–63.

——— & M. KOREKAWA. 1955. Studies on the stability of the radioactive minerals at high temperature. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 165–76.

UKAI, Y. 1955. Thermal investigation of minerals by means of dielectric behaviours. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 185–98.

WATERHOUSE, J. B. 1955. An isoclinal fold on Häckel Peak, Southern Alps, N. Zealand. *Trans. roy. Soc. N.Z.*, **83,** pt. 2, 345–6.

———. 1956. Recent French contributions to the geology of New Caledonia. *N.Z. J. Sci. Tech.*, B, **37,** No. 5, 587–96.

WELLMAN, H. W. 1955. New Zealand quaternary tectonics. *Geol. Rdsch.*, **43,** Heft 1, 248–57.

———. 1955. A revision of the type Clarentian section at Coverham, Clarence Valley. *Trans. roy. Soc. N.Z.*, **83,** pt. 1, 93–118.

WHITEHEAD, T. H. 1955. The Western Longmyndian rocks of the Shrewsbury district. *Geol. Mag.*, **92,** No. 6, 465–70.

WILSON, D. D. 1955. The northern continuation of the Canterbury Plains, Canterbury, New Zealand. *N.Z. J. Sci. Tech.*, B, **37,** No. 2, 126–31.

WILSON, D. D. 1956. The late Cretaceous and the early Tertiary transgression in South Island, New Zealand. *N.Z. J. Sci. Tech.*, B, **37,** No. 5, 610–22.

————. 1956. Note on the geology of the Ant stream Tertiary outlier, North Canterbury, New Zealand. *N.Z. J. Sci. Tech.*, B, **37,** No. 5, 603–5.

WOOLMAN, J. F. 1955. Investigations into the drift deposits near Cannock, Staffordshire. *Proc. Bgham. nat. Hist. Soc.*, **18,** pt. 5, 97–133.

YOSHIZAWA, H. 1955. A suppt. to 'The metagabbroic rocks bearing ferriferous minerals in the Ryoke zone, Japan'. *Mem. Coll. Sci. Kyoto*, ser. B, **22,** No. 2, 238–41.

OBITUARY NOTICES, 1956

HENRY GOULD BUSK, a member of the Association since 1911, died at the age of sixty-five on 22 March 1956. He went up in 1908 to King's College, Cambridge, took Parts I and II of the Natural Sciences Tripos in 1911 and 1912, and graduated B.A. in 1912. He spent most of his working life during the next thirty years as geologist in the oil industry, working for various interests in Peru, Persia, Sinai, Burma, Venezuela, Trinidad, Ecuador, Kenya and Tanganyika.

His outstanding pioneer work in Persia has received tribute elsewhere (*Proc. Geol. Soc. Lond.*, 1541, 1956). No less important for the future of geology in that country was the help and encouragement he gave to young men in 1923–4, when he was directing a number of survey-parties staffed by a dozen youngsters, only three of whom had any previous experience. He did all he could to foster responsibility, and after helping a party off to a good start, he would leave them to carry on for months without supervision. He would then visit them again and would critically discuss the progress made and the planning of the work ahead, and presently he would indulge his love of geological argument. He was a doughty opponent, and when, as occasionally happened, new evidence seemed to cast doubt on one of his working hypotheses, he would defend his ideas with the utmost tenacity; he was open to conviction, but his young men soon discovered that the only way to convince him was to have a good case and argue it logically, objectively and, above all, in friendly fashion, otherwise he would break off the discussion.

All this was excellent training, and although more than thirty years have gone by since he left Persia, his treatment of the young entry set an example which has been followed to this day. F.D.S.R.

WILFRED NORMAN EDWARDS, formerly Keeper of Geology at the British Museum (Natural History), collapsed and died on Hitchin Station on Monday, 17 December 1956, at the age of sixty-six. He had been a Member of the Association since 1920.

Educated at Cambridge County school, Edwards was later a scholar at Christ's College, Cambridge. He joined the staff of the British Museum (Natural History) in 1913, but served with the R.A.M.C. in the Balkans during the first world war and did not resume his museum work until 1919.

As the first palaeobotanist to be appointed by the Museum he had the formidable task of organising and arranging the vast fossil plant collections, of which he had an encyclopaedic knowledge. He was the author of some forty papers, mainly palaeobotanical, including the 'Guide to Fossil Plants' and the 'Guide to the Early History of Palaeontology', all written in his own admirable style. He will also be remembered for the many papers, catalogues and guides he inspired others to write and then edited, and for the assistance and encouragement, mingled with criticism, he was always so ready to give. He attended many Field Meetings of the Association, often as Director.

Edwards was made Deputy Keeper of Geology in 1931 and Keeper in 1938, continuing in this office until June 1955.

He served on the Council of the Geological Society from 1936–45, as Secretary from 1940–4 and as Vice-President from 1944–5. He was awarded the Lyell Fund of the Geological Society in 1933, and the Lyell Medal in 1955. He served as President of Section C at the British Association meeting at Bristol in 1955. H.M.M.W.

HAROLD BENJAMIN HARWOOD, who joined the Association in 1938, died suddenly at his home in Leicester, on 13 May 1956. Mr. Harwood, by profession an engineer, was a keen amateur geologist and collector. For a short time during World War II he worked on a hydro-geological survey of Leicestershire on behalf of the Ministry of Agriculture and Fisheries. His collection, containing much local material, is now in the Museum and Art Gallery, Leicester. G.J.S.

W. E. HOWARTH, F.G.S., F.M.A., was appointed assistant in the Department of Geology in the National Museum of Wales in 1920 and became Assistant Keeper in 1942. He received his geological training under Prof. Swinnerton at Nottingham. His original intention was to become a teacher and he accordingly took an active interest in the school pupils who visited the Museum, either individually with specimens they had collected, or as members of organised parties. He served as President of the Biological and Geological Section of the Cardiff Naturalists Society and was a member of the South Wales Institute of Engineers, but his main interest was the Geologists' Association whose excursions he attended over a long period. He was elected in 1921 and became a Life Member. During the last years of his life he was troubled at the prospect of failing eyesight and died on Easter Sunday 1956. Under his will the Geologists' Association benefits to the extent of about £1100, including a donation to the Illustrations Fund, and the National Museum of Wales to the extent of about £1000.

F.J.N.

DUNCAN LEITCH, who was well known for his work on non-marine lamellibranchs from the Coal Measures, died suddenly after a tragic illness on 12 January 1956, only a week after the death of Sir Arthur Trueman, his co-worker and mentor.

Born in Glasgow in 1904, Leitch was educated at Woodside Higher

Grade School and the University of Glasgow, where he graduated in 1926. He held some junior teaching posts at that University until his appointment as lecturer in 1938, a post which he then occupied until 1947, when he succeeded T. Neville George as Professor of Geology and Geography at the University College of Swansea.

Leitch was a patient and gifted teacher, whose enthusiasm for geology was communicated to his students not least by his inborn friendliness and natural ability in kindling inspiring discussions on diverse topics, both in the field and in the laboratory. He was obviously happy to sacrifice a great deal for teaching work while at the University of Glasgow, but this was a characteristic trait in him.

His research work was mainly concerned with the palaeontology and stratigraphy of the Coal Measures. His chief interests in palaeontology were variation in fossil assemblages and the associated problems in systematics, together with the application of this knowledge to stratigraphical and economic problems. There is no doubt that the appointment of Sir Arthur Trueman to the Chair of Geology at Glasgow in 1937 greatly stimulated his interests in these fields. Leitch collaborated with J. Weir on the zonal distribution of non-marine lamellibranchs in the Coal Measures of Scotland (1936), and published original accounts of variation studies on the *Carbonicola* fauna of the Midlothian Fifteen Foot Coal (1936) and the 'Anthracomyas' of the basal *similis-pulchra* Zone in Scotland (1940). His other main papers dealt with the Upper Carboniferous rocks of Arran (1941); variation in *Naiadites* from the Lower Carboniferous of Scotland (1942); some Coal Measure fossils from Yorkshire (jointly with W. R. Barker, 1947); and Biometrics and Systematics in relation to Palaeontology (1951). Leitch was awarded the Murchison Fund of the Geological Society of London in 1947. He was also a Fellow of the Royal Society of Edinburgh, and served for eight years as Secretary of the Geological Society of Glasgow. He joined the Geologists' Association in 1947. He had a profound belief in the cultural value of geology as part of a liberal education, and this was reflected to a considerable extent in his teaching. He was the author of *Geology in the Life of Man* (1945) in the Thinker's Library. He took an active interest in the British Association, and became Secretary of Section C (Geology) in 1951.

Throughout his tenure of the Chair of Geology at the University College of Swansea, Leitch played an active part in University life and administration, and was a very popular figure in the College, thoroughly at home in its Welsh atmosphere. He carried out the onerous duties of Dean of the Faculty of Science with distinction from 1949 to 1951. In recent years he had been deeply involved in designing a new Department of Geology in the Natural Science building which was due to be erected, and even during the later stages of his grave illness he still insisted on devoting much time to this project. It was a tragedy that he did not live to occupy his new department in 1956, particularly as its completion marked an important stage in the advancement of geology at Swansea, coinciding with the maturing of some of his own research activities. Leitch had undertaken a detailed re-investigation of the faunas and stratigraphy of certain portions of the South Wales Coalfield, partly in collaboration with colleagues and members of a research team he was beginning to gather around him, and much of this work was well advanced at the time of his death.

Duncan Leitch will always be remembered for his deep-rooted integrity and wealth of sympathetic understanding. His views were at all times tempered with modesty and good humour, while the dual qualities of kindness and unselfishness permeated his entire character, endearing him to all. He will be sadly missed by his numerous friends, particularly at Glasgow and Swansea. He is survived by his widow and young son.

G. T.

HARRY LIONEL SARGENT died at his home at Southborough, Tunbridge Wells, on 14 March 1955, at the age of eighty-four. He had a long and distinguished professional career in metalliferous mining in the days when so many new fields were being opened up by British Engineers in all parts of the world. From 1885 to 1889 he gained his early experience in this country, particularly in Northumberland, while articled to the late C. Algeron Moreing, with whom he went to South Africa. First to the Rand for some years and later, in 1893, to what was then Mashonaland, where he was the Resident Engineer for his firm, Messrs. Bewick, Moreing & Co., at Umtali until 1896. This was in the very early days of developments in South Rhodesia when conditions were by no means settled. Mr. Sargent himself went on foot from Beira to Umtali. From 1896 until 1904 he represented his firm in reporting on enterprises in New Zealand (at Auckland and at Dunedin), and later in Western Australia (at Coolgardie and at Kalgoorli). In 1905 he became associated professionally with the late W. R. Feldtmann with whom he was in partnership from 1911 until his retirement in 1924. Together, at various times, they visited properties in Canada, the United States and Siberia.

Mr. Sargent had, from his earlier years, been on the roll of the Institution of Civil Engineers and on that of the Institution of Mining and Metallurgy. Of the latter body he became a Student Member at its foundation in 1892, an Associate Member in 1895 and a Full Member in 1902. In recognition of his services to the profession and to the Institution, the Council conferred on him the distinction of Honorary Membership in 1953. He joined the Geologists' Association in 1890 and was a Life Member.

Those who had the good fortune to know Mr. Sargent will remember his sterling qualities and his devotion to good works. He was esteemed by a wide circle of friends, both in his profession and in the quiet surroundings of his home at Southborough where he spent his later years. S. W. S.

GEORGE SLATER, who died on 27 January 1956, first made contact with the Association when he acted as Director of a Field Meeting to Claydon and Ipswich in 1907. Joining the Association in 1919, for nearly half a century, first as an amateur and later as a professional, he spared no pains in furthering its aims by addressing meetings, leading excursions and proclaiming to students and others the advantages that membership offered.

Born at Sharrow, near Ripon, he was brought up in the Brontë country, where life was fully as hard as the novelists depicted and schooling entailed much sacrifice. After being trained as a teacher (St. John's College, York) he became a schoolmaster, first in Northumberland and subsequently in East Anglia. In due course he entered the Royal College of Science (Imperial College), obtained the Diploma of Associateship in Geology, and later that of Membership of Imperial College by research. He graduated in the University of London, proceeded to M.Sc. and eventually to D.Sc. At Professor Watts's invitation he joined the staff of the Imperial College, and served for many years as Demonstrator and Lecturer, being particularly successful with junior students, generations of whom from the Royal School of Mines and the City and Guilds Engineering College remember him with gratitude and affection.

During his youth Slater had the great privilege of seeing the Officers of H.M. Geological Survey at work. These masters of field-mapping, in particular J. R. Dakyns and R. H. Tiddeman, befriended him and encouraged him to make geology his hobby; and, impressed by their meticulous work, he made accurate measurement his own watchword. He was, indeed, intolerant of slipshod ways in either teaching or research (as witness his paper in the *Geol. Mag.*, 1912, which left the supposedly Pleistocene 'Ipswich Man' without a leg to stand on).

Residence in East Anglia brought exceptional opportunities for studying glacial deposits, not only those to be seen in oft-discussed sections (as along the coast near Cromer) but also extensive exposures resulting from engineering and building operations. He was thus led to carry out original work in glaciology, in which subject he became an authority. The mode of origin of the various deposits and especially the nature of their intense disturbance had been highly controversial subjects. After plotting many of the lengthy exposures, he found that certain definite structural patterns were characteristic: and he came to the conclusion that they must have a genetic significance. In order to gain further insight into these problems, he not only studied ice-action in the Alps, but also joined the Oxford University Expedition to Spitsbergen in 1921 as glaciologist. He also broadened his experience by investigating glacial phenomena in Denmark, Germany, Canada and South Africa. Observations made during his travels abroad enabled him to produce papers on the relation between air temperature and rate of melting of ice, the composite nature of drumlins, and the Dwyka tills and pavements, among other subjects. His accounts of the Mud Buttes of Alberta, the cliffs of Möens Klint and Lönstrup in Denmark and of Rügen in Germany (illustrated by detailed drawings) were of particular importance. Many of these examples of highly disturbed deposits had hitherto been regarded as due to earth-movements, but he was convinced that, like the similar occurrences of contorted and sheared material in East Anglia, they revealed the effects of movements in ice charged with dirt bands. So closely did they conform to the patterns which he had seen in englacial and subglacial material that he spoke of them as 'Glacial pseudomorphs' and frequently used the expression 'Glacial tectonics' (our PROCEEDINGS, 1926 and 1927). His annotated drawings of the longest and best exposed of these sections—the seventeen-mile stretch of cliffs where the Norfolk coast cuts across the Cromer Moraine—proved too expensive for reproduction during the lean inter-war years. It is satisfactory to record that he presented them to the Library of the Geological Survey and Museum, where they may be consulted.

He was awarded the Murchison Fund by the Geological Society of London in 1928 and in 1950 he was the recipient of the Association's Foulerton Award.

In 1897 he married Anne, daughter of the late Archibald Irwin of Tynemouth, who survives him. P.G.H.B.

FREDERICK SMITH, B.A., F.G.S., a former Town Clerk of Coventry, who died in April 1956, had been a member of the Association since 1926.

Starting as a boy in the service of the Coventry City Council he was attracted to the legal side and by diligence and hard work qualified as a barrister. Much later in life he decided to become a solicitor and studied to pass the necessary examinations. Mr. Smith was an outstanding personality whose gifts and qualities were recognised by his promotion to Town Clerk, a position he held for twenty-two years until his retirement in 1946.

During his service with Coventry Council he saw many changes and a great development in the city he loved so well. He had many difficulties to face and overcome, not the least being the work of restoration following the heavy enemy air attack on 14 November 1940.

In appreciation of his outstanding services he was made an Honorary Freeman in 1946, only the seventh Honorary Freeman that the city has known in its long history.

Mr. Smith was very active in the preservation of local records and wrote the book *Coventry—600 Years of Municipal History*.

His tastes were simple. He was a great walker, often setting out by himself to walk twenty or thirty miles. It was, no doubt, his enjoyment of the open air and the beauties of the countryside which attracted him to the Geologists' Association and he attended many of its Field Meetings. He was a Life Member. It was largely due to his help that the Midland Group was formed in 1937.

Though somewhat austere and stern in appearance no one had a kinder heart and many of his friends remember gratefully the help and encouragement he so often gave them.

Mr. Smith was cremated in Edinburgh, where he had settled on his retirement, but by his own wish his ashes were scattered on the green at Stivichall near Coventry, a hamlet he had been instrumental in preserving.

Mr. Smith leaves a widow and a son, who is farming in Scotland.

A. L. L.

SIR ARTHUR E. TRUEMAN died in what we now look upon as merely middle age. Yet in his sixty-one years he had achieved great things and many honours which would justifiably cause those who had never met him to think of him as at least an octogenarian. Most members of the Geologists' Association, which he joined in 1919, already know the factual highlights of his career and it is, therefore, only necessary to refer to these very briefly here.

Trueman was born at Nottingham in April 1894 and was educated at High Pavement School and University College, Nottingham. He graduated in 1914 with first-class honours in geology and then took his M.Sc. two years later and his D.Sc. in 1918. He was appointed an Assistant Lecturer at University College, Cardiff, in 1917 and three years later became the head of the new geology department at University College, Swansea. In 1930 he was given the professorship of what had, by this time, grown under his guidance into the combined department of geology and geography. In 1933 he accepted the Chaning Wills Chair in Geology at the University of Bristol and in 1937 he moved from there to Glasgow as Professor of Geology. In 1946 he was appointed full-time deputy-chairman of the University Grants Committee and became its chairman in 1949. He was compelled by ill-health to resign from the latter post in 1953. Trueman was the recipient of the Murchison Fund of the Geological Society of London in 1925, the Bigsby Medal in 1939 and the Wollaston Medal in 1955. He was awarded the Gold Medal of the South Wales Institute of Engineers in 1933. In 1942 he was elected a Fellow of the Royal Society and was President of the Geological Society from 1945–7 and President of Section C of the British Association in 1948. He was chairman of the Geological Survey Board for over ten years (1943–54). In 1951 he was created K.B.E. He was also an Honorary LL.D. of four universities, viz.

Rhodes, Glasgow, Leeds and Wales. He served as a member of the Elliott Commission on Higher Education in West Africa (1943–4).

As a student Trueman came under the influence of Professor H. H. Swinnerton, who cultivated his early interest in the natural sciences and guided it into the field of palaeontology in which he was later to attain great eminence. His initial researches on the fauna and stratigraphy of Jurassic rocks were given an impetus by his contacts with such amateur geologists as Buckman and Tutcher. His work on the Lias and his varied palaeontological studies of ammonites, gastropods and the lamellibranch Gryphaea brought him right to the forefront as a palaeontologist while yet very young. Although as time went on he became renowned for his work on the Coal Measures he never lost interest in these early fields of study and from time to time in later years he published, for example, papers on evolutionary problems related to Gryphaea and also the Lias of Skye. His papers in the wider realm of palaeontology on such subjects as lineage and orthogenesis were also linked with these early detailed studies.

His appointments in South Wales brought him into direct contact with the Coal Measures. With the knowledge and technique acquired from his earlier work and the initial guidance of practical mining engineers, such as J. H. Davies, who had noted by collecting fossils of non-marine lamellibranchs, that types were indicative of stratigraphical horizons, Trueman embarked on the researches which made him world famous and established a zonal succession in Coal Measures which enabled the identification and correlation of coal seams to be determined over wide areas. His subsequent work, much of which was accomplished in collaboration with his research students and his other colleagues in the coalfields, covered wider aspects of Coal Measures geology than the palaeontological successions. His paper jointly with Emily Dix and D. Farr Davies on 'Boreholes in Cwmgorse Valley', published in 1928 by the South Wales Institute of Engineers, was probably the means by which the great economic value of his palaeontological discoveries were first fully recognised by the coal mining industry. In this connection it is interesting to note that the National Coal Board are now sinking the shafts of an important new anthracite mine (Abernant Colliery) at the site of these boreholes which were drilled thirty years ago. This new mine might in some ways be regarded as a worthy memorial to Trueman's work in South Wales. The publication in 1954 of the comprehensive book *The Coalfields of Great Britain*, edited and partly written by him, was a fitting culmination to the work which he pioneered.

Sir Franklin Sibly, who was head of the geology department at Cardiff during part of Trueman's period there as a young lecturer and was Principal of University College, Swansea, in the period 1920–6, was possibly the first to appreciate fully Trueman's great ability as a teacher and administrator. Many of his old students at Swansea, Bristol and Glasgow are today famous geologists; they as well as their lesser-known contemporaries readily acknowledge their great indebtedness to Trueman for the enthusiasm with which he inspired them early in their careers. He had a great gift for explaining complex matters simply and of getting down to the crux of a problem. He was always happy and ready to help and encourage amateur organisations by giving lectures, leading field excursions and acting as editor or secretary or treasurer. He published books on geology for school-children and a textbook for the more advanced pupils at grammar schools. In the field he would always illustrate the relations of geological features to scenery and landscape and thereby make the subject very much alive and real, particularly to the non-specialist. Members of the Geologists' Association who attended Field Meetings under his direction can recall vividly his abilities in this direction, e.g. excursions to the Cardiff District (1920), Swansea District (1924) and the Gloucester District (1934). Arising initially from lectures and field excursions which he organised in the Bristol region he wrote a book on the *Scenery of England and Wales*, illustrated to a great extent by his own drawings. His natural and quiet wit livened his discourses and his ability to provoke original ideas frequently turned his lectures to Honours students into discussion classes which instilled a real and deep interest in the topics, and a will to do original research. He never lost interest in his past students and took great delight in maintaining contact with them, especially with those of his early days; it did not matter whether they had attained fame or were relative failures, they were always his personal friends.

Trueman had an artistic hand and mind. His illustrations, whether of fossils or of landscape, either in publications or on the blackboard, were always a joy to behold. Many of his friends treasure the originally illustrated Christmas cards which they received from him year by year. In his later years in particular he derived a lot of pleasure from water-colour painting of landscapes and from the subsequent joy it gave friends to receive these beautiful pictures as presents.

Trueman's duties as deputy chairman, and later as chairman, of the University Grants Committee in the crucial post-war years, when schemes of vital importance in the expansion and development of British universities were being evolved, were exceptionally heavy. His organising ability, breadth of outlook, power of leadership and high integrity helped greatly to get these schemes formulated. In the words of Sir Emrys Evans in commending him for the Honorary LL.D. Degree of the University of Wales, 'There is no British University that would not freely acknowledge its debt to him'. Under the continued strain, however, his health gave way and despite his courage and determination he had ultimately to resign these posts.

Even in his suffering and with illness gradually but relentlessly paralysing him he turned again to geology and obtained much pleasure from reading, writing and editing works on the subject, but his joint monograph with John Weir on Upper Carboniferous mussels, although well advanced, was not completed by the time of his death. Those of us who saw him or received letters from him during the latter part of his illness could notice that alert and brilliant mind still active and endeavouring to conquer the physical disabilities which were now upon him. In those last years of infirmity he was blessed with the constant care and attention of Lady Trueman who was always there beside him. Their only son, Mr. E. R. Trueman, is on the staff of the Zoological Department at the University of Hull. Trueman died on 5 January 1956. R.O.J.

ARTHUR GEORGE DAVIS, whose name comes to mind whenever mention is made of the British Eocene, was born at Beckenham, Kent, on 14 March 1892, and lived in this district all his life, except during service in the Royal Naval Air Service during the first world war and in industry during the second. As a boy he attended the local school until the age of fourteen; this was his only formal education, but he showed a vivid and burning interest in natural history, and came to know and collect the plants, insects and fossils still to be found in a countryside not yet built up into Greater London. On leaving school he entered the family business, being apprenticed as a carpenter, but his interest in natural history, particularly fossils, continued to grow, in spite of very little encouragement of any kind.

It was at this period that he timidly showed at the Croydon Natural History Society, his collection of flint sponges from the Chalk to the veteran palaeontologist G. J. Hinde, who was known to young Davis from his monographs, of which he had already acquired second-hand copies. Alas! the great man confessed that he had long ceased his studies of these fossils, and years afterwards Davis told the writer of his intense disappointment.

During the 1914–18 war Davis was for a time stationed at Minster in the Isle of Sheppey, Kent, and it was there that he made the acquaintance of the famous coast-section of London Clay, the London geologist's own type-section, with which he was to be so intimately associated in his later career. Challenged by a sentry (as was the writer many years later) for trespassing on a forbidden zone of the cliffs and foreshore, young Davis was brought before an officer, who having heard his explanation, told him brusquely that an airman's eyes should be looking skywards, not towards the ground, and then dismissed him.

After the war he commenced his studies of the Chalk microfossils of Surrey, but soon became attracted to the Eocene through the influence of the late Arthur Wrigley. Together the two began a revision and re-investigation of the palaeontology and associated problems of the British older Tertiaries, Wrigley specialising in the study of the mollusca, Davis in that of the microfossils, particularly the polyzoa. So began the partnership which was the nucleus of the unofficial 'Second London Clay Club', initiating a renewed interest in the Eocene unparalleled since the days of Sowerby, Wetherell and Forbes. Together the two friends investigated the Eocene in sections old and new, at first near London, then farther afield, the results appearing in a long list of papers, and reports of Field Meetings in our PROCEEDINGS. All this work was done in Davis's own time, with the microscope in evenings after his day's work; sometimes at the Museum on Saturday afternoons, and in the field most week-ends and holidays.

In 1935, after unemployment in the years of the economic depression, Davis abandoned his ordinary work, and accepted a temporary commission to overhaul the Tertiary fossils in the collections of the Geological Survey. It was a big step to take, but at the end of this work he was recommended to Dr. G. M. Lees of the Anglo-Iranian Oil Co. Ltd. Here his first, tempory, assignment (1936) was the identification and age-determination of the largely recrystallised radiolaria in the red and green cherts of the Tethyan mountain-zone. He did so well at this difficult task that he was placed on the staff as palaeontologist, a position he filled with success until his retirement in December 1953. During the war years he was moved about the country on the British oil discovery programme. On retirement he carried out part-time work with the collections of foraminifera at the British Museum of Natural History, where he had long been a familiar figure, and was also occupied with oil consultancy. It was in these later years that his own researches were largely on the Pleistocene and Recent land mollusca, and several papers and a fine collection testify to this. He died peacefully in his sleep early on 1 March 1957, suddenly and without previous illness, having been actively engaged at his scientific pursuits the day previous.

Davis was a fine collector with an unsurpassed eye for a fossil in the field, and a genial director at Field Meetings. He was tireless in taking bulk samples, which he carried home, washed, and sifted for tiny treasures with rare patience. He loved old books, and a lifetime of collecting had gained him a magnificent library. His published works are numerous; besides the Eocene and its fossils he wrote on William Smith and other worthies of early days, old maps, pre-Tertiary radiolaria and foraminifera, the Surrey Chalk and Holocene mollusca. At the time of his death he had just completed his share of a joint work with the author on the London Clay, and it is hoped to publish this eventually. Of his many papers his work on the London Clay of Sheppey (1936) is perhaps that by which he will best be known: his own favourite was his 'English Lutetian Polyzoa' (1934) and the high-water mark of his association with Wrigley was their recognition of an English Cuisian in the Isle of Wight (1937); all in our

PROCEEDINGS. A member of many learned Societies, he was a Vice-President of our Association (1956), and had received the Foulerton Award (1928), had received the Murchison Fund of the Geological Society of London (1943), and was a Past-President of the Conchological Society. He had been elected a member of the Association in 1919. He was made an Honorary Associate of the British Museum (Natural History) in 1948.

He was ever encouraging and helpful to beginners, and many will remember his kindness in this way.

Few have achieved so much with such initially poor opportunities, and remained, as he did, a lovable character; the writer knew no one who disliked him. He leaves a widow and three married daughters, to whom our sympathy is extended. G.F.E.

An Aeromagnetic Survey of the Church Stretton Area, Shropshire

by FREDERICK A. HENSON

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ABSTRACT: Recent years has seen the rapid development of magnetic survey from the air, and airborne surveys have proved of immense value in mineral and oil surveys. The airborne magnetometer has also proved of value in areas covered by extensive superficial deposits or thin sedimentary veneers. In the Church Stretton area, however, the distribution of the various rock types is well known and this survey provides an illustration between known geology and an aeromagnetic map. The method of survey is outlined, and the magnetic profiles over the major geological features are discussed. This is the first aeromagnetic map of an area in the British Isles to be published and is due to the courtesy and co-operation of Hunting Geophysics Ltd. who carried out the survey.

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1. INTRODUCTION

THE USE of magnetic measurements in geophysical surveying is not new. As early as the seventeenth century prospectors, in search of iron ore, used a form of magnetic compass. It is, however, only within the last fifteen years that very sensitive magnetic instruments, capable of being carried and operated in an aeroplane, have been developed. These differ from the Schmidt balance and other mechanical devices used in ground surveys, since they use electronic principles to measure and record the magnetic field in which they operate. The development of such instruments was stimulated during the last war by the need to detect submerged submarines from the air. Since then the ever increasing demand for oil and economic minerals has led to further improvements in the airborne magnetometer and the introduction of even newer methods of geophysical survey and prospecting.

This paper outlines the principles of the airborne magnetometer used in the first aeromagnetic survey to be made in this country. The Church Stretton area was chosen mainly because of its varied and classical geology (Fig. 1), together with the interesting geologic and topographic associations it exhibits. This survey was carried out by Hunting Geophysics Ltd. some years ago, who have made all the information freely available and have specially redrawn the maps for publication.

2. AIRBORNE MAGNETOMETER SURVEY

(a) The Magnetometer

The principle upon which the airborne magnetometer is designed was discovered a quarter of a century ago in Austria. The instrument measures the total intensity of the geomagnetic field at any point, the horizontal and vertical components not being measured independently. This instrument consists of a 'flux-gate' measuring element which is aligned in a position parallel to the earth's field by two more flux-gate elements.

The flux-gate measuring element used on this survey was of the twin coil type. In this, two similar coils are wound over high permeability cores of mumetal; the coils are placed parallel to each other and so connected that the fields produced by the energising alternating currents cancel. A secondary coil is wound over this twin coil, the result being that the voltage induced in this secondary coil measures the magnetic unbalance in the mumetal cores. In other words, when this arrangement of coils is placed in an external magnetic field, the induced voltage of the secondary coil will indicate the strength of that external field. When used in aircraft this measuring element, and two other flux-gates, are mounted mutually at right angles in a gimbal system which can rotate about two axes. The measuring element is aligned parallel to the earth's field by the two positioning flux-gates acting through servo-mechanisms on the two axes of the gimbal system. The detector head is placed in position within the tail unit of the aircraft.

The instrumentation is designed to record graphically the value of the external magnetic field acting upon the measuring element. With this equipment it is practical to measure changes in this external field of the order of 1 to 2×10^{-5} gamma (Gauss or Oersted $= 10^5 \times$ gamma). Drifts of less than 3 gamma per hour are attainable by the equipment, which maintains accurate recording despite sudden aircraft manœuvring.

(b) Flight Procedure

The aircraft used in this aeromagnetic survey was a Percival Prince. In this aircraft the magnetometer head is built into the tail and the instrumentation is conveniently located in the central part of the fuselage. The flight, or profile lines, are all north to south at a quarter of a mile spacing and were made at a height of 500 feet above ground level. These flight lines, which are shown on the aeromagnetic map, are numbered L.1 to L.25. In addition there are two east–west flight lines T.L.N. and T.L.S. The tie-lines provide datum values for the magnetic readings obtained along the flight route and, by assuming linear variations caused by changes in the total magnetic field, the diurnal drift has been calculated for the flying time between the control lines. In this survey with very short profile lines the amount of drift was extremely small. It is, however, normal procedure to fly twice over fixed points within ten minutes so that diurnal drift can be determined.

The exact positioning of the aircraft whilst recording the total magnetic field is achieved by the use of a ciné camera mounted in the centre of the aircraft. This exposes film at regular intervals so that the track of the aircraft is completely recorded. The magnetometer record is also marked at each film exposure. In addition to automatic recording of the aircraft's track a radio altimeter indicates to the pilot both the actual height of the aircraft at any moment and also records that height. By these means the position of the aircraft in space at any time can be very accurately determined. The altimeter record, corrected for instrument lag, is shown in Fig. 3. This shows how closely the survey aircraft has followed the topography on parts of lines 6, 15 and 23 despite considerable variations of the relief.

(c) Compilation

The first stage in the production of the total intensity map was the accurate positioning of the flight lines with reference to the base map of the area (1:25,000). The magnetic values, correlated for drift and instrumental error, were plotted in their exact positions upon the flight lines and the map was then contoured, the contour interval being ten gamma. Contours at 100, 500 and 1000 gamma are shown by thicker and broken lines.

3. THE AEROMAGNETIC MAP

The first and most striking impression of this magnetic map (Fig. 1) is the clear division of the area into three parts, viz. the north-western area of comparatively low magnetic relief corresponding to the outcrop of the Longmyndian and Carboniferous rocks; a central zone of high magnetic variations corresponding to the Uriconian east of the Church Stretton Fault, and the south and south-east area of low magnetic relief of the

Ordovician, Silurian and Devonian rocks. Thus the magnetic map (Fig. 1) reflects the broad pattern of the geology of this well-known area. A stratigraphical order is adopted for the discussion of the magnetic map and the geology below.

(a) Uriconian

The Uriconian rocks covered by this survey are from Ragleth Hill through Hazler Hill, Hope Bowdler Hill, Cardington Hill, Willstone Hill Caer Caradoc to The Lawley. These are all marked topographic features rising well over 1000 feet to a maximum of 1506 feet at Caradoc Hill. These hills consist predominantly of volcanic rocks, tuffs and breccias. The lavas are mainly acid and intermediate in composition and they are associated with intrusions of dolerite. These rocks give rise to the most marked anomalies within the area surveyed.

On the magnetic map all the outcrops of the Uriconian are clearly defined by marked positive anomalies. At Caer Caradoc and The Lawley the orientation of these magnetic anomalies coincides with that of the outcrop of the Uriconian. The magnetic contour of 2450 gamma on the western margin of these hills is almost straight, whilst the magnetic gradients to maxima of between 2650 and 2700 gamma are steep. By contrast the magnetic contours on the eastern margins of both Uriconian outcrops are more widely spaced. Thus aeromagnetic evidence supports geological evidence of their faulted western margin, with the eastern margins unconformably overlain by younger rocks with no evidence of faulting However, as in all cases of the Uriconian rocks in this area, the magnetic anomalies lie south of the surface outcrop. The implications of this are discussed below.

In the case of the southern outcrop of the Uriconian rocks in this area from Ragleth Hill to Hope Bowdler Hill, the magnetic anomalies have a clear east–west orientation and their maxima lie some one to one and a half miles south of their outcrop area. This southward shift of these maxima as well as those in the Caer Caradoc–Lawley area, may indicate that either the Uriconian rocks have a more southerly development at shallow depth or that the rocks themselves contain more basic lavas with greater magnetic susceptibility than the outcrop. The latter is, however, unlikely. It is suggested that the Uriconian rocks may be massive inclined sheet structures dipping at forty to sixty degrees to the south-east. Further, the magnetic anomaly rising to 2680 in the Rushbury area, which has a clear NE. to SW. orientation, may well be a further eastward extension of the Uriconian beyond the present outcrop which is buried by comparatively thin Silurian deposits.

The two cross-sections shown in Fig. 2 illustrate the form of magnetic profiles from NW. to SE. taken from the Longmyndian across the Church

Stretton Fault to the Silurian. These show marked differences in magnetic profiles despite similar geological sections. In the upper section, from Hope Wood to Harton, the rise in the total magnetic field is both greater and more sustained than in the lower one. In the latter the abrupt rise begins immediately south-east of the fault, which it very clearly indicates. There is also an interesting superficial resemblance between the magnetic and the topographic profiles in this section since both profiles show double maxima in which the magnetic profile is displaced to the south-east. It is likely that the mass of the underlying Uriconian rocks in the lower section is less than the upper.

(b) Longmyndian

These rocks, which occupy the north-west part of the area under survey, provide some contrast to the Uriconian rocks described above. They show little variation in their magnetic properties over the whole of their outcrop, the maximum variation being between 2370 and 2470 gamma, i.e. 100 gamma. Despite this small variation there are features of interest in this area. The first is the clear trend of such small anomalies which do exist, this is from east to west in the Smethcott area in the north and from WSW. to ESE. in the southern outcrop. The second is the increase in the magnetic gradient south-west of Church Stretton as the fault is approached. Clearly the Longmyndian rocks do not reveal the structures recently described (James, 1956) because such sediments are practically non-magnetic.

It is probable that in the Longmyndian of this area the east-to-west anomalies are associated with both mineralised east-to-west faults recorded by James, and also to one or two very minor igneous masses in the neighbourhood of All Stretton. Finally it is extremely likely that, in the northern part of the Longmyndian outcrop covered by this aeromagnetic survey, the sediments are of great thickness. In the southern area the Church Stretton Fault seems to be less marked.

(c) Cambrian

In this area the Cambrian rocks lie east of the Caer Caradoc range and consist of a basal quartzite, followed by sandstones, shales and grits. These Cambrian sediments rest unconformably upon the Uriconian volcanic series and their outcrop forms, with the exception of the Cambrian rocks east of Cardington Hills, a narrow SW. to NE. strip. These rocks are practically non-magnetic and their outcrop is not reflected by the aeromagnetic map in any part of the area. This is also partly due to the fact that any minor variations likely to occur within these sediments would be masked by the stronger magnetic fields associated with the Uriconian rocks which underlie them at a comparatively shallow depth.

(d) Ordovician

The Ordovician rocks, like those of the Cambrian, consist predominantly of non-magnetic shales and flags. Their outcrop is more extensive than that of the Cambrian and is characterised by magnetic anomalies clearly related to the underlying Uriconian beds.

(e) Silurian and Downtonian

Rocks of Silurian age outcrop over a third of the area covered by this survey. They occur in the southern area and form such well-known topographic features as Wenlock Edge and Hope Dale. Lithologically these Silurian rocks vary from the older sandy or conglomeratic deposits laid down along an irregular coastline through shale and calcareous deposits of the Wenlock to the marls and sandstones of the Downtonian. The geology of this area, which has attracted many geologists since the first researches of Murchison, is both well known and recorded in geological literature.

The aeromagnetic map of these Silurian rocks shows a fairly uniform magnetic field with only slight magnetic anomalies. This area is quite clearly formed of non-magnetic sediments of considerable thickness. Only in one area is there any possible indication of the influence of deeply buried Uriconian rocks. This is the elongated small positive anomaly in the Eaton-under-Heywood area. To clarify any relationship which might exist between topography and the magnetic field, parts of the flight lines 6, 15 and 23 have been redrawn as magnetic profiles, together with corrected aircraft flying heights and geological sections (Fig. 3). It can be seen from all three profiles that the effect of topography upon the magnetic profiles is slight. In line 6 there is a slight rise in the total magnetic field over Wenlock Edge whilst in line 15 there is only a very slight rise over both Wenlock Edge and the Aymestry Limestone. In line 23 the magnetic fields are lowered, however, on passing over these limestones.

(f) Carboniferous

The Carboniferous rocks form a triangular outcrop between the Longmyndian and the Uriconian rocks in the northern area of the survey. Unfortunately the aeromagnetic map shows a considerable gap between flight lines 10 and 12 so that the map is not complete in this strip. Despite this the change in the pattern of the magnetism of the Longmyndian and the Carboniferous rocks is quite distinct, although the western boundary is not clearly defined. Over the Carboniferous strata the magnetic field is extremely constant and contrasts with the abrupt change as the Church Stretton Fault and the Uriconian beds are reached.

4. CONCLUSIONS

The first and most important conclusion to be drawn from this aeromagnetic survey is that there are many applications of this method, both in regional surveys and in prospecting. The Church Stretton area contains rocks of a considerable age range and lithology, and it is these factors which clearly combine in making this aeromagnetic map so geologically informative.

The highest magnetic anomalies recorded in this survey are related to the Uriconian rocks; these also form the topographic backbone of the area. The western margins of Caer Caradoc and The Lawley show sharp changes in the magnetic field, thus emphasising the throw of the Church Stretton Fault. They also indicate that the Longmyndian sediments and Carboniferous rocks west of the fault are of considerable thickness. The southern and eastern boundaries are less clearly defined and show that the Uriconian rocks probably underlie the lower Palaezoic formations at shallow depth. These buried Uriconian rocks, which probably have elongated structures, occur in the Rushbury and Eaton-under-Heywood areas.

Traverses across the Wenlock and Aymestry limestones show remarkably little magnetic variation despite variations in relief and flying height. In such areas the sediments are of considerable thickness and the basement rocks are deeply buried; these buried rocks do, however, exhibit the same SW. to NE. magnetism as the Uriconian rocks. Finally the Carboniferous rocks are shown to occur in a clearly defined trough, the eastern margin of which is delineated by the Church Stretton Fault.

ACKNOWLEDGMENTS

The author would like to express his sincere thanks to Hunting Geophysics Ltd. who have freely made available all aircraft and flying records; the company have also redrawn both the maps at their expense and converted what was originally a flying training programme into a very useful contribution to geological knowledge. In particular the author wishes to express his sincere thanks to Mr. P. A. Rankin, Technical Manager to Hunting Geophysics Ltd.

REFERENCES

Bullard, E. C. *et al.* 1955. *Airborne Geophysical Survey.* Hunting Geophysics Ltd.

Cobbold, E. S. 1927. The Stratigraphy and Geological Structure of the Cambrian Area of Comley (Shropshire). *Quart. J. geol. Soc. Lond.*, **83**, 551.

James, J. H. 1956. The Structure and Stratigraphy of part of the Pre-Cambrian Outcrop between Church Stretton and Linley, Shropshire. *Quart. J. geol. Soc. Lond.*, **112**, 315.

Lapworth, C. & W. W. Watts. 1910. '*Shropshire.*' *Geology in the Field.*

Pocock, R. W. & T. H. Whitehead. 1948. The Welsh Borderland. *Brit. reg. Geol.*

Runcorn, S. K. 1954. Airborne Magnetic Surveys. *Nature*, **173**, 281.

Vacquier, *et al.* 1951. Interpretation of Aeromagnetic Maps. *Geological Society of America Memoir*, 47.

DISCUSSION

DR. J. F. HAYWARD congratulated the author on having made a difficult subject both interesting and intelligible to a geological audience. He noted that the traverses had been made in approximately a north–south direction. To the geologist it would appear that a more suitable direction would be roughly at right angles to the strike of the Palaeozoic rocks. He would like Dr. Henson to explain whether in fact the direction of the traverse was significant.

COLONEL H. D. ANTHONY asked whether the type of survey described by the author would be used especially during the International Geophysical Year?

THE AUTHOR, in reply, discussed some of the details of the survey more fully than had been possible in the reading of the paper. As regards Dr. Hayward's question concerning the direction of flight lines the author referred the matter to Mr. P. A. Rankin, Technical Manager of Hunting Geophysics Ltd., who was present and who had had world-wide experience upon these matters. In answer to Colonel H. D. Anthony the author stated that during the 1955–6 Antarctic summer this method of prospecting and survey had been used in the survey of British possessions in that continent and that further extension of the areas surveyed would be probable during the Geophysical Year.

MR. P. A. RANKIN in discussing the question of the direction in which aeromagnetic traverses should be flown said that his company had given considerable thought to the matter in view of the variety of the surveys they had been called upon to perform in many parts of the world.

Three major factors have to be considered:

1. The object of the survey and, therefore, the type of flight pattern required.
2. The dip of the earth's field.
3. The flying problems in the area.

In general, there are two types of aeromagnetic survey: those flown at constant barometric height and those flown at a constant height above ground form (profile flying). In general, areas are flown at a constant barometric height when a study of deep-seated magnetic features is required whereas profile flying applies where near-surface features are to be studied.

The first type of survey is best accomplished by flying traverses at right angles to the regional geological trend irrespective of dip of the field, if the magnetic features are relatively deep-seated all over the area. This is because the magnetic anomalies will generally trend with the geology and they can best be recorded by flying at right angles to their axes.

Complications arise, however, if the magnetic anomalies in the area are caused by near-surface bodies, whether this is incidental or expected. The dip of the field is important here and it should be remembered that the requirement of the survey is to record the total force anomalies as accurately as possible. As one approaches the magnetic equator, so total force anomalies tend to align themselves in an easterly-westerly direction. This state becomes critical when the dip is less than about 40°, and in areas of gentler dip than this, it is generally true that the aeromagnetic traverse lines should be flown in a northerly or southerly direction. The geological trend or the trend of the magnetic bodies to be studied will, however, still influence the anomalies and each area has to be considered on its merits with a view to choosing the most suitable direction to cut the anomalies at a steep angle to their axes.

In surveys where profile flying is required in order to record as much detail as possible, the flying problems influence the choice of flight direction. Ideally, the aircraft (and detector) should maintain a constant height above ground. In areas of rugged topography it may be beyond the capabilities of the aircraft to follow the ground form accurately if flight directions are required to be normal to the topographic grain. A compromise on flight direction might, therefore, be necessary to achieve a reasonably consistent height above ground.

The Cenomanian Limestone of the Beer District, South Devon

by WILLIAM E. SMITH

Received 18 April 1956; read 7 December 1956

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ABSTRACT: In the cliff-sections between Whitecliff (Seaton) and Hooken Cliff (SW. of Beer) the thickness of the Cenomanian Limestone varies considerably. At the rear of Pound's Pool Beach and at the end of a small point on the west side of Beer Beach it is only about one foot thick. In contrast, at Beer Head and Hooken Cliff it is very much thicker, reaching a maximum of nearly thirty feet in the latter place.

These variations in thickness appear to be related to a NNE.-SSW. axis of intra-Cretaceous periclinal uplift passing from Beer Beach to Little Beach (west of Beer Head). The Cenomanian Limestone is thinnest and least complete over the crest of the uplift. The thicker, more complete successions at Beer Head and Hooken Cliff lie on opposite (i.e. ESE. and WNW.) sides of the axis.

There is evidence of intermittent small-scale tectonic activity along the axis before, during and after Cenomanian times. On the other hand the Tertiary fold known as the Beer Syncline appears to have been superimposed on the Cretaceous rocks and structures.

1. INTRODUCTION

THE CENOMANIAN LIMESTONE is the name given to the few feet of sandy limestones which occur between the Upper Greensand and Middle Chalk in South Devon. The stratigraphical position of the formation shows that it represents, at least in part, the much thicker Lower Chalk of the more easterly counties of England. In southern Dorset the Cenomanian consists of blocky grey marly chalk with a well-marked sandy glauconitic basement-bed. This facies persists as far west as Membury (near Axminster) where it is at least fifty feet thick. In the coastal sections about eight miles south of Membury, however, no such deposits are present, the sole representative of the Cenomanian being the above-mentioned sandy limestones. These are not only much thinner than the Lower Chalk of Dorset but, in the sections between Lyme Regis and Sidmouth, they undergo rapid lateral changes in thickness. In places, for example at the extreme western end of Charton Cliff, the formation is absent. In other places, as in the Hooken Landslip, it reaches a thickness of nearly thirty feet. Over most of the outcrop, however, the thickness ranges from one to four feet (Plate 4A).

The Cenomanian Limestone here in South Devon provides us, therefore, with a remarkable example of condensation and lateral change both in facies and thickness. Comparatively little work has been published regarding the formation. Meyer (1874) tabulated and numbered the Cretaceous strata around Beer and gave a faunal list for each of his subdivisions. The beds numbered 10, 11, 12 and 13 by him appear to represent the strata which were later grouped as the Cenomanian Limestone.

In the Geological Survey Memoir relating to the country near Sidmouth and Lyme Regis (Woodward & Ussher, 1911), the description of the beds is based upon observations made by Jukes-Browne. Indeed, this author is responsible for the only published data regarding the lateral variations of the formation (1896 and 1903). He (1903, pp. 130–44) divided it into three subdivisions, A, B and C, each of these subdivisions being characterised by a distinctive lithology and fauna. They were regarded by him as being separated from each other and from the contiguous deposits by erosion-surfaces. Jukes-Browne ascribed the remarkable lateral variation in thickness of his subdivisions to variable depth of erosion during successive erosion-periods. In a footnote (1903, p. 351), however, he suggested that differential (unequal) penecontemporaneous earth-movements may also have been a factor.

The present paper describes in greater detail the lateral variations in the thickness of the Cenomanian Limestone between Whitecliff, Seaton and the Hooken Landslip, west of Beer Head (Fig. 1). It also suggests an explanation for the remarkable lateral variations in thickness which occur between these localities.

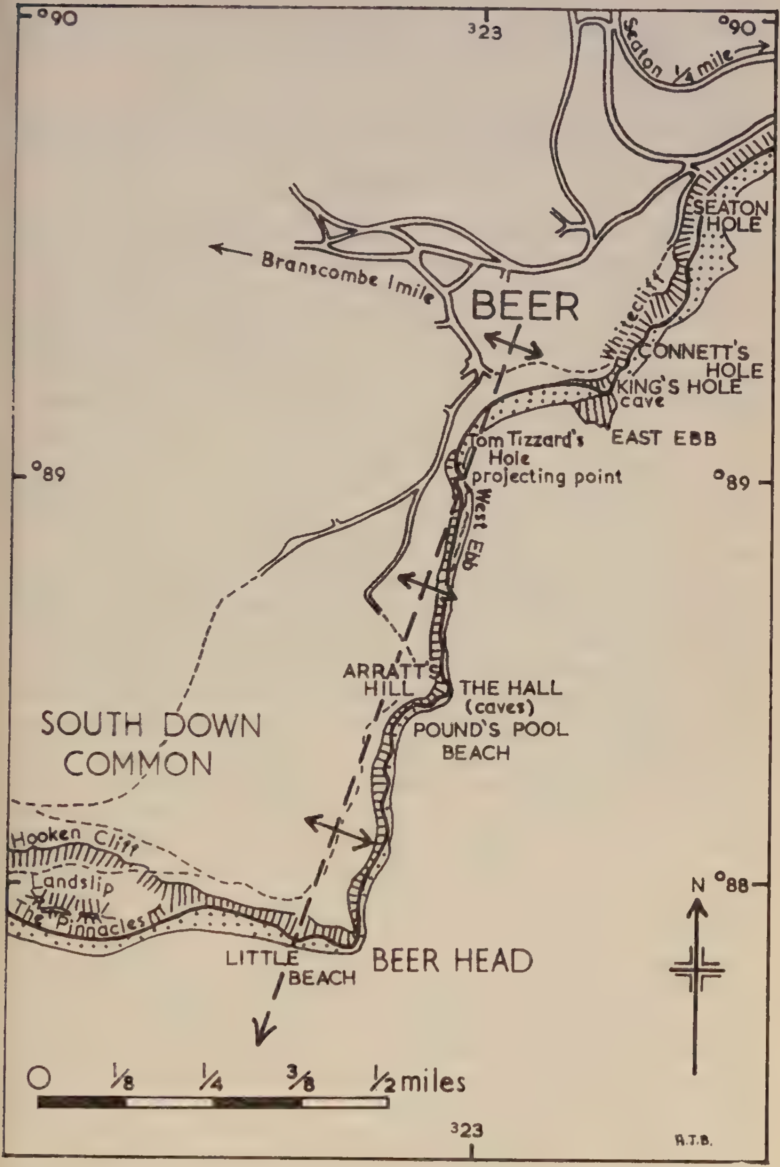


Fig. 1. Locality-map of the Beer district showing position of the axis of intra-Cretaceous earth-movements which influenced the thickness of the Cenomanian Limestone

Many of the features discussed in this paper can be seen in the excellent photographs which accompany Rowe's paper on the White Chalk of Devon (1903).

2. CLIFF-SECTIONS BETWEEN SEATON HOLE AND THE HALL

(a) Whitecliff

At Seaton Hole (30/235896) a conspicuous fault, with a westerly downthrow of at least 200 feet, brings the red Keuper Marl against the Upper Greensand and Chalk exposed at Whitecliff. The Cretaceous rocks have here a westerly dip towards the axis of the Beer Syncline and are magnificently exposed in strike-section alongside the fault-gully. About five feet of Cenomanian Limestone can be seen immediately beneath the whitish chalk of the *Inoceramus labiatus* Zone (*Rhynchonella cuvieri* Zone) of the Middle Chalk but is not easily accessible. Farther south-west, however, where the limestone is brought slightly lower by the westerly dip, it can be easily reached by climbing the Whitecliff rock-fall. At this point the limestone has a total thickness of fifty inches but is partially obscured by chalk-wash from above. For this reason many of the lithological features are more clearly seen in the huge fallen blocks which litter the shore. The cliff-section is important, however, since it shows that the limestone is separated from the contiguous strata by open divisional-planes, i.e. the limestone has sharply defined upper and lower surfaces which are rendered conspicuous by lines of shallow cavities. The base rests abruptly, with strong lithological contrast, upon the calcareous sandstone which forms the uppermost division of the Upper Greensand. Cavities, such as joint-fissures, in the top of this sandstone are often filled with gritty limestone containing Cenomanian fossils. This suggests that a period of erosion preceded the deposition of the Cenomanian. During this erosion-period unconsolidated sand was removed to reveal a joint-fissured surface of calcareous sandstone. The earliest Cenomanian sediments accumulated on this surface and also filled up these fissures.

Another important erosion-plane forms the upper surface of the Cenomanian Limestone which is overlain abruptly by the basement-bed of the Middle Chalk. The latter consists of hard nodular cream-coloured chalk containing a few scattered grains of quartz and glauconite in its lower part. Despite the presence of this sandy material there is never any sign of a passage between the basal Middle Chalk and the underlying Cenomanian Limestone, the junction being always very sharp.

At first sight, the Cenomanian Limestone appears to form a lithological unit bounded at top and bottom by erosion-planes. This view would seem to be supported by the fact that the formation always falls from the cliff in complete blocks. Closer examination shows, however, that it really consists of two very dissimilar limestones firmly welded together. In the Whitecliff section the lower limestone, Division A of Jukes-Browne, is about three feet thick. It is cream-coloured and very fossiliferous, entire and fragmentary lamellibranch shells being particularly abundant and conspicuous. Grains and small pebbles of clear and milky quartz are scattered throughout the limestone but glauconite is very scarce and always of small grain-size. Rounded black detrital grains of tourmaline are not uncommon. These may be large enough to be visible to the naked eye and could be mistaken for particularly dark grains of glauconite.

The uppermost limestone, Division B of Jukes-Browne, is only fifteen inches thick, i.e. less than half as thick as Division A. In contrast with the underlying limestone it contains very few fossils and could not be described as a shelly limestone. Furthermore, in addition to quartz grains it contains comparatively large grains of glauconite which tend to be concentrated locally in pockets. Irregular green and brown streaks, best seen in wave-smoothed blocks, are usually conspicuous in the upper part of this division. These streaks are frequently due to the presence of green-coated superficially-phosphatised masses of limestone lithologically identical with that of the bulk of the bed. Their presence is indicative of limited penecontemporaneous erosion of the limestone antecedent to the main erosion-period which left the upper surface of the Cenomanian as it is seen today.

The junction between the two Cenomanian limestones is always very sharp with no signs of any transition. It is usually marked in vertical sections by a slightly wavy brownish ochreous line which appears to be the trace of an iron-stained phosphatised erosion-surface. This conclusion is supported by the fact that it can be seen cutting across shells in the upper surface of the lower limestone. Unfortunately it has not been possible to examine this surface in plan since the two limestones are so firmly welded together that they never break along their contact.

(b) King's Hole and East Ebb Cave

The westerly dip of the Cretaceous strata brings the Cenomanian down to beach-level on the extreme eastern side of Beer Beach. Just before it disappears under the shingle it is conveniently exposed in and around the small cave (East Ebb Cave) which links this beach with King's Hole. Both of the above-mentioned lithological divisions of the Cenomanian can still be recognised here but their combined thickness is reduced to about two feet. This marked reduction in total thickness is almost entirely due to attenuation of the lower or shelly limestone. For example, in the walls of the cave this division is about one foot thick in contrast with the three feet exposed at Whitecliff above the rock-fall.

(c) West Side of Beer Beach to The Hall

The Cenomanian Limestone, as the western limb of the Beer Syncline, emerges from the shingle on the western side of Beer Beach, a short distance southwards of the small cave known as Tom Tizzard's Hole. It shows an easterly dip but rises very slowly from the beach since the section runs at a small angle to the strike. Its total thickness is only eighteen inches, but the two divisions can be recognised. The hard shelly limestone which forms the lower part is about twelve inches thick. At one point the overlying glauconitic division descends deeply into the shelly limestone but maintains an average thickness of about six inches. As is the case elsewhere, the base of the shelly limestone rests abruptly upon the calcareous sandstone which forms the top of the Upper Greensand.

About twenty yards south-west of Tom Tizzard's Hole the cliff swings into a more westerly direction and then curves round the back of a small rock-fall. Owing to this change in direction the easterly-dipping Cenomanian Limestone rises well above beach-level. As it is traced up-dip, its total thickness increases until just south of the rock-fall it is thirty-two inches thick, with a thickness of nineteen inches for the lower division. The cliff continues to curve round until it forms a small easterly-projecting point separating Beer Beach from a very small cove to the immediate south (Fig. 1). The Cenomanian Limestone, still with an easterly dip, is admirably exposed on both sides of this point and in the sides of the small cove (Plate 4B). The separation of the limestone into two divisions is particularly clear at this locality since many of the shells in Division A are silicified and stand out in relief as a result of air-weathering. The iron-stained erosion-surface separating the two divisions is very conspicuous here and, in addition, a minor erosion-plane appears locally within the uppermost division.

If the Cenomanian Limestone be traced on either side of the small easterly-projecting point a remarkable easterly thinning is observed (Plate 4B). The lower division (A) gradually thins out completely until at the apex of the point only Division B, about a foot thick, separates the Upper Greensand from the basal strata of the Middle Chalk. As on the opposite side of Beer Beach this rapid reduction in total thickness of the Cenomanian Limestone is mainly due to attenuation of Division A.

The thinning out of Division A is, however, quite a local feature since this division reappears in the sections south of the very small cove referred to previously. In this direction the Cenomanian Limestone can be traced southward along the top of a low ledge of Upper Greensand which projects from the base of the cliff. Its total thickness increases gradually, due almost entirely to an increasing thickness of Division A. Still farther south, to the north of the cave-riddled point known as The Hall, the formation descends into the more elevated part of the West Ebb rocks. These rocks lie between tide-marks and the Cenomanian is wave-worn and encrusted with marine growths. It is difficult, therefore, to measure its thickness, but sufficient can be seen to show that the increase in thickness is maintained. The most southerly measurement north of The Hall that can be regarded as reliable gave a total thickness of four feet (Division A three feet, B one foot), i.e. measurements similar to those obtained at Whitecliff.

Summarising the evidence provided by the sections so far described, the Cenomanian Limestone appears to thin towards an area underlying Beer Beach (Fig. 2). The lateral changes suggest that such an area extended in a general NNE.–SSW. direction, i.e. obliquely into the present cliff-line south of Beer Beach. The shelly division of the Cenomanian Limestone appears to thin against a NNE.–SSW. ridge of Upper Greensand, the crest of which lies close to the end of the small easterly-projecting point. The overlying glauconitic division of the Cenomanian Limestone thins slightly when it is traced towards the same region.

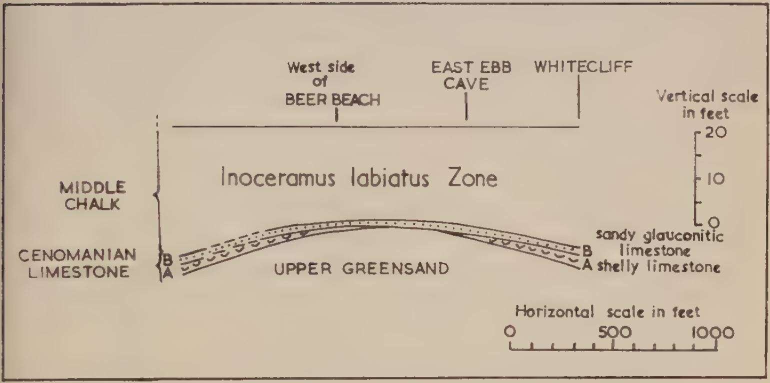


Fig. 2. Diagrammatic section showing the variation in the thickness of the two divisions of the Cenomanian Limestone exposed between Whitecliff and the west side of Beer Beach

3. ISOPACHYTES OF THE CENOMANIAN LIMESTONE EXPOSED ON THE WEST SIDE OF BEER BEACH

Isopachytes of the shelly division of the Cenomanian Limestone were drawn in order to determine the exact orientation of the crest of the ridge. This was rendered difficult by:

(1) The dense marine growths covering much of the limestone south of Beer Beach; these made it difficult to distinguish the two divisions of the Cenomanian. The total thickness of the formation could usually be mea-

sured but this is of little use since it is the sum of two variables, i.e. the varying thicknesses of the two divisions.

(2) The open nature of the divisional-plane separating the Cenomanian Limestone from the Upper Greensand, which made it difficult to fix the exact base of the former. This was most serious when the lower division of the Cenomanian was only a few inches thick.

Most reliance was therefore placed upon measurements made in the very small cove south of the small point on the west side of Beer Beach. In this cove the Cenomanian Limestone is not covered by marine growths and the separation into two divisions is very clear. Moreover, since the sections along the sides of this cove are approximately at right angles to the pre-

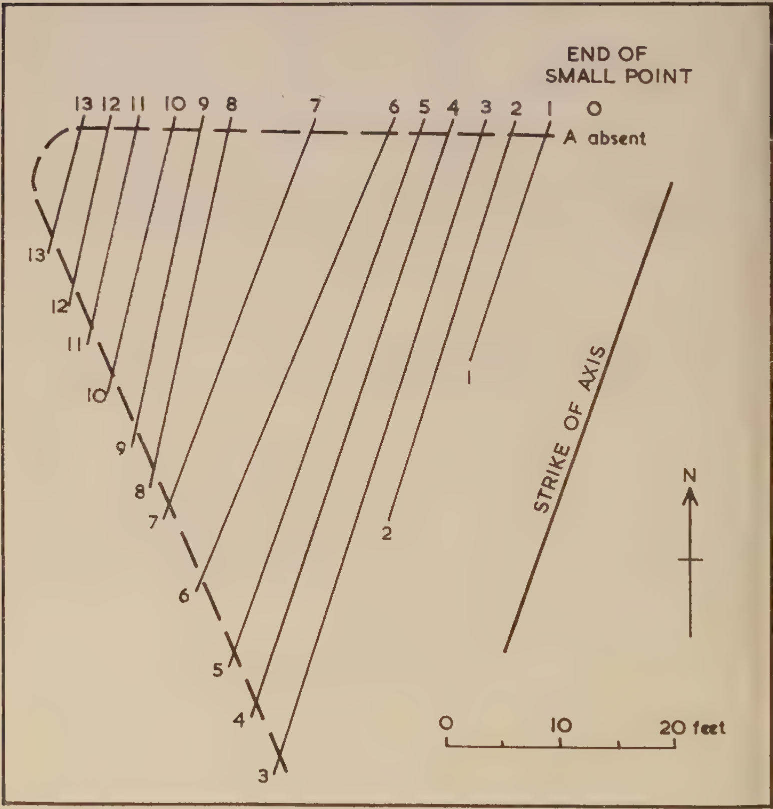


Fig. 3. Isopachytes of the lower division (A) of the Cenomanian Limestone exposed in the small cove on the west side of Beer Beach, drawn at intervals of a change of thickness of one inch

sumed axis the rate of attenuation is comparatively rapid. The isopachytes drawn from the measurements obtained in this cove (Fig. 3) showed that the maximum rate of thinning occurs towards an axis running NNE.–SSW. This confirms the deduction made earlier, viz. that the crest of the ridge in the Upper Greensand runs obliquely into the West Ebb cliff-line in that direction.

4. CLIFF-SECTIONS SOUTH OF THE HALL

(a) Pound's Pool Beach

When produced towards the SSW. the axis suggested by the isopachytes passes along the back of Pound's Pool Beach and emerges from the cliffs overlooking Little Beach, between Beer Head and the Hooken Cliffs. Pound's Pool Beach is situated south of the cave-riddled point known as The Hall. In these caves the Cenomanian Limestone resembles that seen in the Whitecliff section. Its total thickness in the caves is about four feet six inches, the lower shelly division being about three feet thick. South of the caves the cliff-line swings rapidly towards the west. Because of its easterly dip the Cenomanian Limestone therefore rises in the cliff and passes over the rear of the beach well above beach-level. As it is traced up-dip its total thickness decreases until it is ultimately reduced to about one foot. This attenuation is again largely due to a rapid thinning-out of the shelly division so that the crest of the ridge in the Upper Greensand would appear to maintain its direction at least as far south as Pound's Pool Beach (Fig. 1). The direction of attenuation is, however, westerly, i.e. towards the western flank of the ridge (Fig. 2). This confirms that the crest passes obliquely into the West Ebb cliffs since the attenuation is in the opposite direction to that seen in the small point on the west side of Beer Beach.

(b) Pound's Pool Beach to Beer Head

Between Pound's Pool Beach and Beer Head the Cenomanian Limestone gradually increases in thickness. The increase in thickness is less obvious than towards The Hall, since the cliff-line and the crest of the ridge are now less divergent. Nevertheless, in the embayment north of the actual headland its total thickness is again about four feet. At the headland itself a rapid increase in thickness can be observed, the formation reaching a maximum of about thirteen feet (Plate 5 and Fig. 4). The upper division (B) is about two feet six inches thick and weathers with a rough pitted or honeycombed surface. It consists of a hard limestone containing quartz and glauconite concentrated together into irregular pockets. This irregular distribution of quartz and glauconite is presumably responsible for the characteristic honeycomb weathering since it is the sandy glauconitic patches which stand out in relief. Green-coated limestone pebbles are particularly abundant at the top of this bed which, as elsewhere, is overlain abruptly by the basal Middle Chalk.

The lower division (A) is about twelve feet thick, a thickness which contrasts strongly with those measured north of the headland. The top of this division is marked by a conspicuous layer of green and brown-stained limestone pebbles. This pebble-bed passes down into a hard gritty and shelly limestone not unlike that seen in the caves at The Hall. This limestone, however, passes down with no obvious break into calcareous grit which contains pebbles of milky quartz, black tourmaline and chert up to four millimetres in diameter. The coarse nature of this grit contrasts with the underlying Upper Greensand from which it is separated by a well-marked open divisional-plane. Notwithstanding the coarse nature of the grit it is very fossiliferous and contains fossils generally similar to those found in the upper part of the division. Conspicuous among the fossils are the remains of a large coral-like branching polyzoan, *Ceriopora ramulosa* Michelin. These polyzoa are particularly abundant at the very base and render the junction with the Upper Greensand extremely conspicuous. They become less frequent upwards and appear to be absent from the upper part of the division. The polyzoan skeletons are poorly preserved and are worn as if transported and rolled. Since they are often six inches or more in length it would seem that they are not likely to have travelled any great distance. Cavities within the skeletons are filled with fine-grained chalky calcium carbonate. In contrast, borings drilled into them by

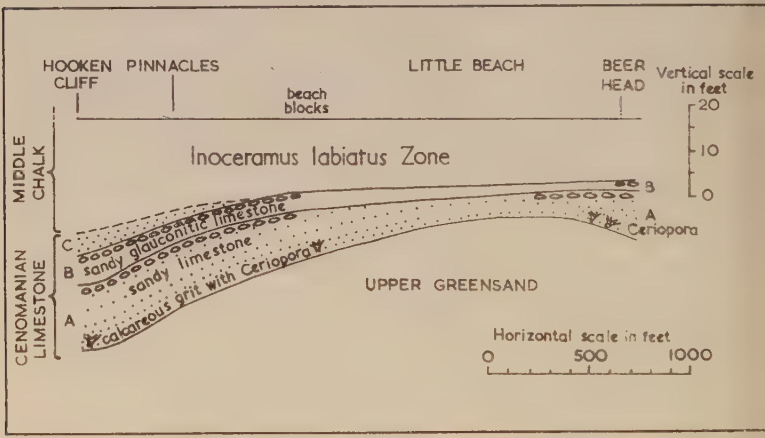


Fig. 4. Diagrammatic section showing the variation in the thickness of the three divisions of the Cenomanian Limestone exposed between Beer Head and Hooken Cliff. In each case the top of the *I. labiatus* Zone is assumed to be horizontal and the effects of Tertiary folding have been eliminated

Lithophaga are now filled with coarse sand. There is no doubt that the polyzoa lived in areas of clear shallow water and were washed into their present position when the accumulation of Cenomanian grit began. They may indeed have lived on or near the crest of the sandstone ridge which undoubtedly existed nearby at this time.

The coarse Cenomanian grits originally had a wider distribution in the Beer area but are now mainly preserved in crevices and fissures in the top of the Upper Greensand. Presumably the grit was not washed away from the Beer Head region since this area was a depression lying to the south-east of the postulated ridge. In this region the deposition of grit was succeeded without a break by deposits of shelly gritty limestone similar to Division A elsewhere.

There is, however, no sudden increase in the sand-content within Division A at Beer Head such as one would expect if grits on the crest of the ridge were undergoing erosion. The thickness of grit overlying the crest of the ridge may have been comparatively small so that the amount of sand removed was not large. On the other hand, the rate of erosion over the crest could have been comparatively slow. Indeed the erosion of the calcareous grit may have provided the quartz grains and pebbles which are everywhere scattered throughout the Cenomanian limestones. The anomalous association of large detrital grains and fine-grained calcium carbonate which characterises these limestones would then be explained.

(c) **Beer Head to the Hooken Landslip**

Westwards from Beer Head the Cenomanian Limestone rises in the cliff above Little Beach. It is magnificently exposed above a small cave near the new sewer-pipe. The roof of this cave is the base of the coarse Cenomanian grit and is studded with large *Ceriopora*. Farther west the Cenomanian Limestone is inaccessible and either deeply air-weathered or decalcified. It is clear, however, that the coarse Cenomanian grit thins out westwards until the thickness of the Cenomanian Limestone as a whole is reduced to about seven feet (Fig. 4). The upper division, characterised by its honeycombed appearance, is about the same thickness as at Beer Head, viz. about two feet. The marked attenuation is therefore again largely due to a reduction in the thickness of the lower division. The attenuation occurs in the region where the crest of the NNE.–SSW. ridge described above should emerge over Little Beach. Nevertheless the amount of attenuation is much less than at Beer Beach or Pound's Pool Beach, i.e. the shelly limestone division is not reduced to one foot or less as it is in those localities. The importance of the ridge therefore appears to have decreased towards the SSW., i.e. it presumably had a low whale-backed form. Unfortunately the absence of exposures at the opposite (NNE.) end of the axis prevents complete proof of this deduction. The attenuation over Little Beach, is, however, followed by a rapid increase in thickness once the crest of the ridge has been crossed. Huge fallen blocks, partly buried in the shingle at the western end of Little Beach, show that the coarse calcareous grit with abundant *Ceriopora* reappears and the Cenomanian Limestone attains a thickness of at least sixteen feet. This increase in thickness is maintained towards the WNW. for in the large slipped masses in the Hooken Landslip, known as the Pinnacles, and near the old Beer Stone adit in the near-by Hooken Cliff, the Cenomanian is nearly thirty feet thick (Fig. 4). A detailed account of the development of the Cenomanian in this area will be given in a subsequent paper. For present purposes it is only necessary to state that the lower division is like that at Beer Head but considerably thicker, viz. about eighteen feet. The overlying Division (B) is also considerably thicker reaching a maximum of nearly six feet. Furthermore, the layer of green and brown stained pebbles at the top of Division B is not overlain by the normal basement-bed of the *I. labiatus* Zone. Instead it is overlain abruptly by comparatively soft, very sandy, glauconitic chalk up to six feet thick. This bed was termed Division C of the Cenomanian Limestone by Jukes-Browne (1903). It passes up with no apparent break into the Middle Chalk but contains Cenomanian fossils, especially in its lower part. Some of these fossils are phosphatised and have undoubtedly been derived from earlier deposits, but others, such as *Orbirhynchia wiesti* (Quenstedt), appear to be indigenous. Division C, therefore, seems to be a passage-bed between the Cenomanian and Turonian in the Hooken area. The bed is of very local distribution. For example, it is completely absent in the fallen blocks at the western end of Little Beach, although so well shown in the Pinnacles, only a short distance farther west.

5. THE CAUSE OF THE LATERAL VARIATIONS IN THE THICKNESS OF THE CENOMANIAN LIMESTONE

The remarkable variations in the thickness of the lowermost division of the Cenomanian Limestone could be explained two ways:

(a) Under shallow-water conditions a greater thickness of sediment would accumulate on the flanks of a *pre-existing* ridge than over its crest. Such a ridge could have been the result of the irregular deposition of the Upper Greensand in the form of an elongated sand-bank (Fig. 5a). Any ridge which influenced the thickness of the Cenomanian Limestone did not, however, consist of *sand*. The presence of Cenomanian sediments in joints and fissures at the top of the Upper Greensand shows that the ridge must have consisted of jointed calcareous *sandstone*, i.e. it was not a sand-bank as this term is generally understood. A *sandstone* ridge (Fig. 5b) could have been produced by the differential erosion of the Upper Greensand *before* the accumulation of the shelly limestones. The crest of a ridge formed in this way would be the area in which this erosion was *least* drastic, a greater thickness of Upper Greensand having been removed from the flanks. It is difficult, however, to suggest any reason for the position and orientation of such a ridge.

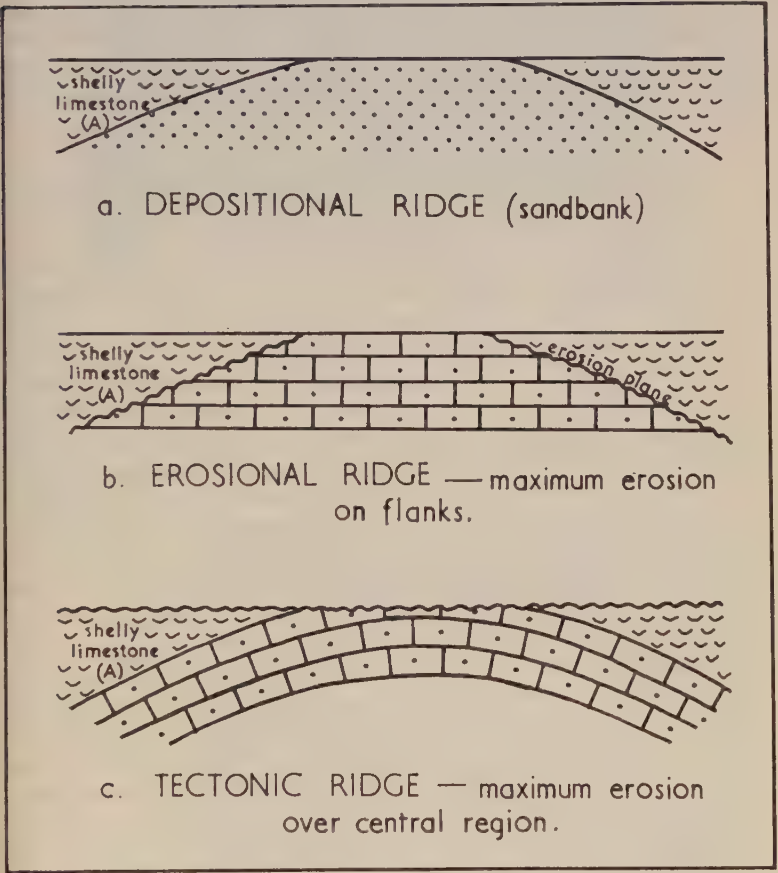

shelly limestone (A)
a. DEPOSITIONAL RIDGE (sandbank)
shelly limestone (A)
erosion plane
b. EROSIONAL RIDGE — maximum erosion on flanks.
shelly limestone (A)
c. TECTONIC RIDGE — maximum erosion over central region.

Fig. 5. Diagrams illustrating three methods which could lead to variation in the thickness of a deposit such as Division (A) of the Cenomanian Limestone.

(a) Deposition of shelly limestone adjacent to a pre-existing ridge produced by irregular *deposition*.

(b) Deposition of shelly limestone adjacent to a pre-existing ridge produced by irregular *erosion*.

(c) More uniform deposition of shelly limestone followed by particularly severe erosion over crest of ridge produced by *tectonic uplift*.

N.B. Erosion as in (c) occurred *several* times both before and after the deposition of the shelly limestone.

(b) The erosion which *followed* the deposition of the shelly limestones could have removed the whole of this division from the crest of a ridge produced by localised tectonic uplift (Fig. 5c). The orientation of such a ridge could be easily explained by involving vertical movements along a NNE.–SSW. axis. It will now be shown that there is indeed sufficient evidence suggesting that such localised small-scale tectonic activity was an important factor responsible for lateral variations in the thickness of the Cenomanian. This conclusion is supported by evidence suggesting intermittent movement along the axis before, during and after Cenomanian times.

6. EVIDENCE OF TECTONIC MOVEMENT

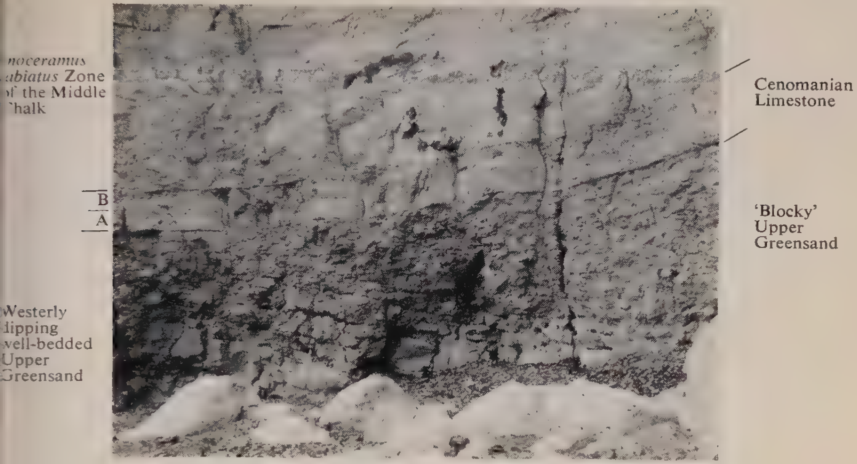
(a) Relationship between the Cenomanian Limestone and the Upper Greensand

There appears to be a flagrant unconformity between the Upper Greensand and the Cenomanian Limestone on the western side of Beer Beach. The angular discordance is best seen when looking southwards towards the small point which separates the beach from the small cove immediately south of it (Plate 4 A). The Cenomanian Limestone and the overlying chalk have an easterly dip here, whereas the Upper Greensand dips in the opposite direction. Small-scale current-bedding can be seen in some of the inclined strata of the calcareous grit which forms the uppermost part of the Upper Greensand. This indicates that the general or overall inclination is not a depositional dip, i.e. it is not diagonal or large-scale false-bedding, but is a true tectonic tilt.

At this locality the lower division of the Cenomanian Limestone would appear to thin out against the western flank of an anticline in the Upper Greensand. In other words the sandstone ridge postulated above could have originated as a result of local anticlinal uplift in late Albian or early Cenomanian times. Unfortunately for purposes of observation, both north and south of the small point, the cliff-section runs mainly along the strike of the beds. For this reason it is difficult to obtain further evidence of an anticline or to demonstrate the existence of an eastern limb. Nevertheless, the variations in the thickness of Division A, especially the increase in thickness when it is traced towards The Hall, would suggest that its crest lies near the end of the small point.

(b) Cenomanian Sediments Filling Fissures in the Upper Greensand

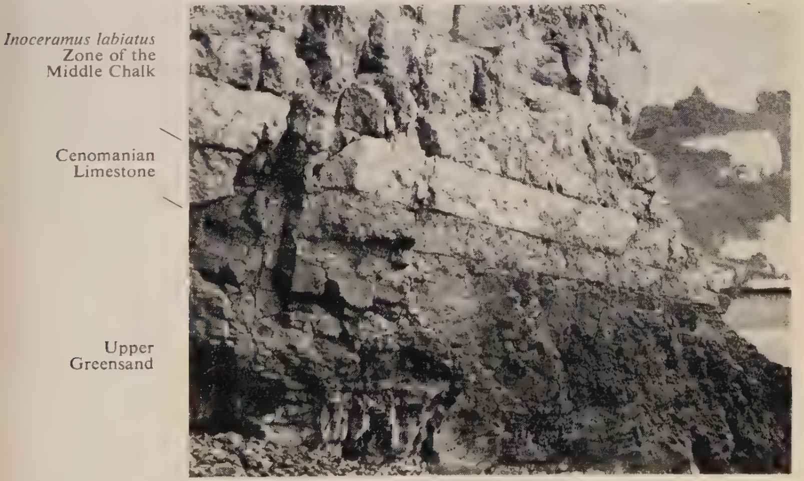
The Cenomanian sediments which occur within crevices and fissures on the uppermost part of the Upper Greensand are much more sandy than the immediately overlying Cenomanian Limestone. Fossils collected from this sandy interstitial material include *Cyclothyris compressa* (Lamarck) and poorly preserved polyzoan fragments which resemble *Ceriopora*



A. The unconformable junction between the Cenomanian Limestone and the Upper Greensand on the west side of Beer Beach, viewed southwards.

Contrast the well-bedded *westerly*-dipping Upper Greensand under the hammer with the overlying blocky Upper Greensand.

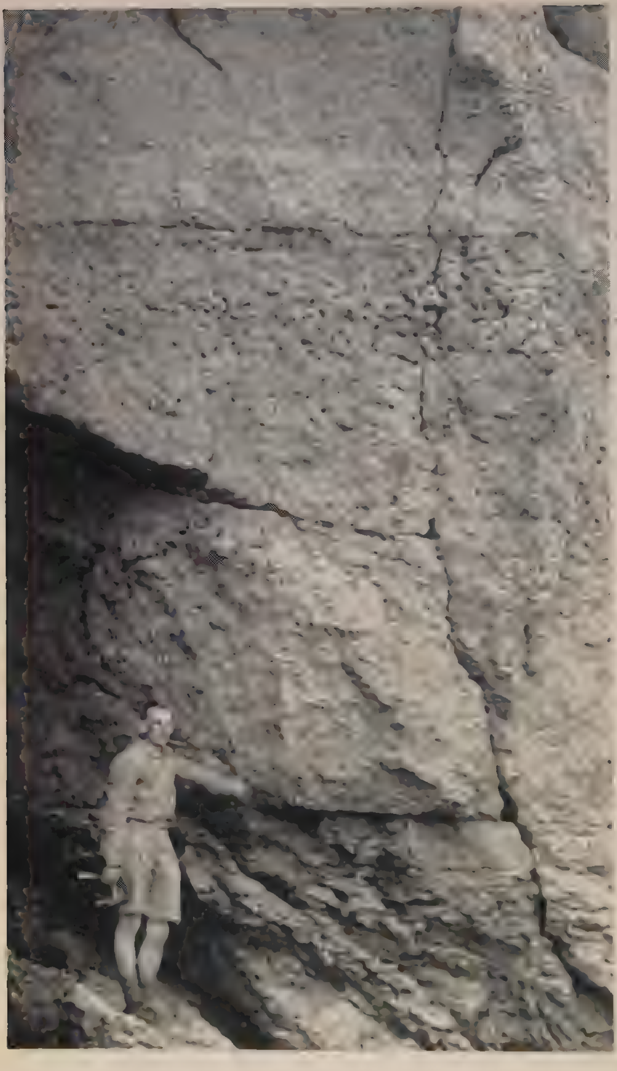
Note that the easterly attenuation of the *easterly*-dipping Cenomanian Limestone is mainly due to the thinning of its lower division (slightly paler than the upper division in the photograph)



B. The eastern end of the small point on the west side of Beer Beach, looking northwards.

The Upper Greensand at the base of the section is overlain by the Cenomanian Limestone which is bounded above and below by open divisional-planes. The overlying Middle Chalk (*I. labiatus* Zone) has a conspicuous basal bed which is also bounded by open divisional-planes. The Cenomanian Limestone thins eastwards and is only about one foot thick at the end of the point

(*Photographs by E. L. Martin.*)



The thick Cenomanian deposits at Beer Head.

The lower division (A) is about 12 feet thick and is separated from the underlying Upper Greensand by a conspicuous open divisional-plane.

The upper division (B) is about 2 feet thick and has a rough appearance due to honeycomb-weathering. The nodular chalk of the *I. labiatus* Zone is separated from the underlying Cenomanian Limestone by another conspicuous open divisional-plane

To face p. 129]

ramulosa Michelin. These fossils are particularly characteristic of the very sandy basal part of the Cenomanian in areas such as Beer Head where the formation attains a much greater thickness. This suggests that the sandy Cenomanian deposits were originally deposited over a much wider area in the neighbourhood of Beer. As a result of intra-Cenomanian anticlinal uplift these sandy beds were eroded from the crestal region of the fold. The sandy material which had penetrated into crevices and fissures in the underlying rocks was, however, preserved.

(c) The Nature of the Uppermost Beds of the Upper Greensand

The uppermost beds of the Upper Greensand often have a very blocky appearance, the spaces between the blocks being filled with Cenomanian sediments (Plate 4A). In many cases these blocks appear to be due to a rough mural-jointing which was developed before the deposition of the Cenomanian. On the other hand, in at least two places, viz. at the back of the small cove on the west side of Beer Beach and in King's Hole, the blocky appearance cannot be explained in this way. The individual blocks seen in these exposures are several inches long and well rounded. They are irregularly oriented as if forming part of a boulder-bed. This feature is most marked in King's Hole, at a place where the underside of the uppermost Upper Greensand is exposed in a small ledge which projects from the cliff-face. The individual boulders appear to be joint-bounded masses of calcareous grit which have been rounded by current-action. They are not developed beneath the Cenomanian Limestone where its lower division is extremely thin or absent, but become noticeable where this horizon thickens. On the other hand they are not conspicuous in places where the Cenomanian Limestone is very thick. This suggests that they are joint-bounded blocks which were washed from the crest of a low sandstone ridge. Evidently they were not moved far from the crest of the ridge and were rounded mainly by current-scour. The process outlined above could have resulted from local anticlinal uplift of the Upper Greensand along the postulated axis. This movement must have been earlier than the intra-Cenomanian uplift referred to under **(b)** above (page 128) since the early Cenomanian sandy sediments are found within the crevices *between* the boulders.

Beds containing sandstone pebbles occur at lower levels in the Upper Greensand. One of the most conspicuous can be examined in the large projecting mass of sandstone which separates King's Hole from Connett's Hole. This pebble-bed occurs about eighteen feet below the top of the Upper Greensand and contains numerous flat ellipsoidal pebbles of glauconitic sandstone and numerous shell-fragments derived mainly from *Exogyra* and other oysters. This pebble-bed was undoubtedly produced by the penecontemporaneous erosion of the near-by Upper Greensand. The pebbles might well have been derived from the region of uplift postulated above. This would indicate movement along the axis during the accumulation of the Upper Greensand itself. Unfortunately the pebbly horizon is carried well below beach-level by the Beer Syncline. It is therefore not possible to confirm this hypothesis by demonstrating the presence of erosion-planes at the appropriate horizon nearer the presumed anticlinal crest.

(d) The *Inoceramus labiatus* Zone of the Middle Chalk

The lower beds of the *Inoceramus labiatus* Zone also thin as they are traced down the sides of the small easterly projecting point on the west side of Beer Beach. In other words these beds thin as they are traced towards the crest of the presumed anticline in the Upper Greensand. As examples, the basement-bed of the Middle Chalk, a hard rough nodular chalk containing scattered grains of quartz and glauconite, thins from two and a half feet to about one foot when traced towards the eastern end of the above-mentioned point. The overlying bed of cream-coloured nodular chalk thins from six feet to four feet when traced in the same direction. Again, the soft grey chalk containing few nodules, which Jukes-Browne correlated with the Beer Stone, is only three feet thick at the end of the point, whereas its thickness at the rear of Beer Beach is nearly five feet. Furthermore, open divisional-planes within this *I. labiatus* chalk increase in number as it is traced towards the end of the point. These divisional-planes appear to represent minor erosion-surfaces similar to those bounding the Cenomanian Limestone. Taken in conjunction with the attenuation of the beds these erosion-planes strongly suggest intermittent uplift along the anticlinal axis in early Turonian times. This conclusion accounts, at least in part, for the abundance of rounded pebbles of chalk within the *I. labiatus* Zone. Many of these pebbles could have been derived from the crest of the uplift during the periods of erosion suggested by the erosion-planes.

The attenuation of the lower part of the *I. labiatus* Zone as it is traced from The Hall to the rear of Pound's Pool Beach (Jukes-Browne, 1903, p. 438) provides further evidence of movement along the axis during Turonian times.

(e) The Chalk above the *Inoceramus labiatus* Zone

In the area under consideration the chalk above the *I. labiatus* Zone has been partially removed during post-Cretaceous erosion. It is also partly concealed beneath dense vegetation or exposed in inaccessible vertical cliff-sections. Measurement of the thicknesses of the zones above that of *I. labiatus* can therefore only be made occasionally and then only over short distances. It is consequently very difficult to detect any effects the anticline may have had upon deposition after early Turonian times.

The scarcity of chalk-pebbles and the persistence of marl-bands in the zone of *Terebratulina lata* suggests that penecontemporaneous erosion was not important during its accumulation. The conspicuous marl-bands, termed the two feet and four feet bands by Rowe (1903), can be traced throughout the Beer Cliffs and, as far as can be judged, maintain a practically constant thickness. On the other hand, as Rowe has shown (1903, p. 46), the overall thickness of the zone is much greater in the Hooken cliffs, about one mile to the south-west of Beer Beach. It is possible, therefore, that the zone thins towards the postulated axis although the absence of Chalk over a wide area on the eastern or upthrown side of the Seaton Hole Fault prevents any confirmation of this.

The small remnants of the Chalk zones above that of *Terebratulina lata* which have escaped erosion are insufficient to prove any later movements along the axis. The *Holaster planus* and *Micraster cor-testudinarium* Zones are well exposed in Annis' Knob, a small but conspicuous bluff which overlooks the north side of Beer Beach. The chalk in this bluff contrasts very strongly with that belonging to the underlying *T. lata* Zone in that it is extremely nodular. The nodules consist of silicified chalk and stand out prominently from the air-weathered surface. Although occasionally containing thin wisps of greyish flint they appear to be quite distinct from the lines of black flint which also occur in the bluff. The exact origin of these nodules of silicified chalk is not clearly understood but they could be chalk-pebbles which were silicified at some period after their formation. If this is the correct interpretation the nodules would indicate frequent periods of erosion such as could result from intermittent movement along the postulated axis. It must be conceded, however, that this view is rather speculative, particularly as the zones in question are not present in the section on the west side of Beer Beach.

7. THE SOUTHERN END OF THE AXIS OF INTRA-CRETACEOUS UPLIFT

It has been suggested earlier in this account that the importance of the axis decreased SSW. of Pound's Pool Beach. This would suggest that the uplift was periclinal. The comparatively thick Cenomanian deposits at Beer Head and Hooken Cliff appear to have been deposited on opposite sides of the southern end of the region of periclinal uplift (Fig. 3). Their relatively great thickness suggests that they accumulated in areas which were either tectonically stable or subject to intermittent down-sagging complementary to upward movements along the axis. It is very difficult to evaluate the importance of each of these two possibilities. All that can be said with certainty is that both the Beer Head and Hooken Cliff regions became repositories for much of the material eroded from the crest of the intervening ridge. For example, the abundant limestone pebbles at the top of both Division A and Division B in these two regions provide significant evidence of the erosion and redeposition of Cenomanian sediments.

Clear-cut erosion-surfaces are, however, present in both the Beer Head and Hooken Cliff sections. Indeed the upper surface of the Upper Greensand and the top of Division B of the Cenomanian Limestone are erosion-planes throughout the whole area discussed in this paper. This shows that erosion was not always restricted to the postulated region of uplift but occasionally assumed a more regional character. It should be noted, however, that even in those cases where an erosion-surface is very widespread, the effects of erosion become more drastic as the axis of uplift is approached.

8. THE RELATIONSHIP BETWEEN THE AXIS OF INTRA-CRETACEOUS UPLIFT AND THE BEER SYNCLINE

Finally it remains to consider the relationship existing between what may be termed the Beer Beach minor axis and the axis of the synclinal fold usually referred to as the Beer Syncline. The latter appears to be a much larger, stronger structure of Tertiary (Alpine) age which has been superimposed upon the Cretaceous rocks and structures. At present there is little information available. All that can be said is that between Little Beach and Beer Beach the axis of intra-Cretaceous uplift lies entirely within the western limb of the Beer Syncline. Farther to the NNE. the limited exposures tend to suggest that the Beer Beach axis passes into the eastern limb of the Beer Syncline. In other words the axis of the later Tertiary folding may lie slightly athwart that of the earlier intra-Cretaceous movements.

CONCLUSIONS

The variation in the thickness of the Cenomanian Limestone between Whitecliff and Hooken Cliff is related to a NNE.–SSW. axis of intermittent intra-Cretaceous uplift. Whenever upward movements occurred along this axis a low elongated whale-backed submarine ridge was formed. The crest of this ridge was subjected to current-scour and, probably, wave-attack. As a result of this erosion previously deposited sediments were removed from the crest of the ridge so that the sediments were either reduced in thickness or completely removed. It is of course possible that the original thickness of sediments over the axis may have been less than in near-by areas. The evidence of repeated erosion, however, suggests that the removal of sediment, in the manner suggested above, was a very important factor and largely responsible for the *variation* in the thickness of the Cenomanian Limestone. The evidence of penecontemporaneous erosion, apparently related to intra-Cretaceous movements along the same axis before and after Cenomanian times, lends further support to this conclusion. Furthermore, in the South Devon coast-section between Sidmouth and Lyme Regis there is evidence of other regions of intra-Cretaceous uplift similar to that described above. The author is now engaged upon the elucidation of the tectonic history of two such areas. One of these is situated at the extreme western end of Hooken Cliff (Branscombe Mouth). The other area lies near the extreme western end of Charton Cliff, about four miles east of Seaton. In both these areas the Cenomanian Limestone is either absent or extremely thin compared with its thickness a short distance from the presumed axes of uplift.

It is apparent therefore that the phenomena described in this paper do not represent an isolated case but form part of a much more widespread set of geological events in South Devon, the true story of which will emerge with further research. It can, however, be stated that the small overall thickness of Cenomanian deposits in South Devon is probably due to regional current-scour, as suggested by Jukes-Browne. On the other hand, the more local lateral variations in thickness are largely the result of differential erosion controlled by small intra-Cretaceous earth-movements.

ACKNOWLEDGMENTS

The author wishes to thank Dr. W. F. Fleet for his helpful criticism of the contents of this paper and for many fruitful discussions on the Cretaceous rocks of South Devon. He also wishes to thank Mr. A. J. Barber for drawing the figures and Mr. E. L. Martin for the photographs used in the preparation of Plate 4.

REFERENCES

JUKES-BROWNE, A. J. & W. HILL. 1896. A Delimitation of the Cenomanian. *Quart. J. geol. Soc. Lond.*, **52**, 99–178.

———. 1903. The Cretaceous Rocks of Britain. II. The Lower and Middle Chalk of England. *Mem. geol. Surv. U.K.*

MEYER, C. J. A. 1874. The Cretaceous Rocks of Beer Head and the Adjacent Cliff-sections. *Quart. J. geol. Soc. Lond.*, **30**, 369–93.

ROWE, A. W. 1903. The zones of the White Chalk of the English Coast. III. Devon. *Proc. Geol. Ass., Lond.*, **18**, 1–52.

WOODWARD, H. B. & W. A. E. USSHER. 1911. Geology of the Country near Sidmouth and Lyme Regis. *Mem. geol. Surv. U.K.* (2nd Edn.).

DISCUSSION

THE PRESIDENT welcomed the speaker's detailed description of one of the tectonic features that characterised the area. He drew attention to the extent to which these submarine ridges affected the fauna; for example the Hooken ridge, to the west of that described by the speaker, apparently represented a marked barrier to the asteroids and echinoids of the early Turonian. He wondered whether in the absence of diagnostic fossils there was any real evidence of the date of the material piped down between the blocks of Upper Greensand. Somewhat similar occurrences probably explained the Lower Cenomanian ammonites found below the top of the Upper Greensand at Punfield Cove and elsewhere.

MR. J. M. HANCOCK also congratulated the author on his detailed study of this area in Devon. Such work in a district where these rocks are relatively well exposed could have applications over a wide area.

The President had pointed out that at Punfield near Swanage undoubted Cenomanian fossils could be found in soft greensand within the hard conventional Upper Greensand. In the Stour Gap area of north Dorset also, one could find examples of *Schloenbachia* in cracks in the Upper Greensand. In fact this phenomenon of down-piping of marine Cretaceous, resting on submarine erosion surfaces into the beds beneath, could be found in many parts of north-west Europe. It certainly occurred in the Senonian of Ireland and the Cenomanian and Turonian of northern France.

The speaker questioned whether it was necessary for the blocks of Upper Greensand to have actually been moved. It was possible for burrowing organisms to bring down sediments with them so that the younger sediments totally surrounded blocks of the earlier rock. This process is seen with unusual clarity in the coast sections at St. Jouin in Seine-Maritime. In the Cenomanian there, relatively pure chalk marl has developed patches of much harder rock due to recrystallisation of the calcite. Such a rock may be truncated by an erosion surface topped by very glauconitic and slightly sandy chalk marl. Burrowers from this glauconite-rich sediment tunnelled into the rock below. Their individual tracks can be found some feet below the erosion-surface. Nearer this surface their paths were used in common with other burrowers so that there is a solid stream of the glauconite brought down from above. The hard concretionary patches have been avoided and the glauconite streams sweep around them, accentuating them still further.

When leading a field meeting of the Association in the Seaton district in the summer of 1955, the author had outlined a relationship between the distribution of the Beer Stone, Division C, and his axes of uplift. Would he care to outline his present opinions on this subject?

THE AUTHOR, in his reply, expressed his satisfaction in hearing that the President had reached the conclusion that submarine ridges of tectonic origin were important features of the Cenomanian sea-floor in South Devon. He agreed that the fauna of the early Turonian Chalk west of the Hooken (or Branscombe Mouth) ridge differed from that of the equivalent strata around Beer. The Author did not agree, however, that the ridge was a barrier, in the sense that it was a feature which prevented or hindered faunal migration. The ridge must have been a comparatively local feature lying between areas of the early Turonian sea-floor on which different environmental (palaeoecological) conditions existed; the conditions on the western side of the Branscombe Mouth ridge being particularly suitable for certain asteroids and echinoids.

In reply to the President's second point the Author explained that, despite a careful search, he had not found any ammonites in the sediments piped down between the blocks of Upper Greensand, presumably because the fissures were too small to admit the larger fossils. Whilst agreeing that in the absence of ammonites it is difficult to date the sediments precisely the Author considered them to be of Cenomanian age because (a) they contained *Cyclothyris compressa* (Lamarck) and (b) their lithology resembled that of the coarse-grained sediments at the base of the thick Cenomanian Limestone at Beer Head. He agreed that the presence of *Ceriopora* fragments could not be taken as proof of Cenomanian age.

In reply to Mr. Hancock the Author said that he did not consider boring organisms as responsible for the production of the blocky Upper Greensand described in the paper. The blocks may have been originally produced by the patchy recrystallisation of the calcareous cement or were formed by the development of a rough mural jointing. The orientation of some of the blocks was, however, consistent with the view that, in places, they had been subsequently disturbed.

With regards to the relationship between the Beer Stone, Division C, and axes of uplift the Author said that this would be fully described in a subsequent paper but in answer to Mr. Hancock's request he would summarise his remarks made during the 1955 Summer Field Meeting in the Seaton district.

Division C, whether it be classed as of late Cenomanian or early Turonian age, is a local basement bed of the Middle Chalk. It occurs in regions lying between tectonic ridges and adjacent to areas in which the Middle Chalk overlaps against early Cenomanian sandstones (Hooken Landslip) or against the calcareous sandstones at the top of the Upper Greensand (Humble Point and Charton Bay). It is not developed in such sections, as that between Whitecliff and Beer Beach, in which the Middle Chalk does not come into direct contact with sandstones. The sandy nature of Division C is therefore due to the reworking of sandy sediments removed from the crest of a tectonic ridge.

The Beer Stone north of the Hooken Landslip appears to have accumulated in the central part of a basin bounded on the east by the tectonic ridge described in the paper and on the west by the Branscombe Mouth ridge.

Summer Field Meeting in South Devon and Dorset

20–27 August 1955

Directors: W. E. SMITH, D. V. AGER, D. J. SHEARMAN

Report by WILLIAM E. SMITH

Received 6 April 1956

THE OBJECT of this field meeting was to study, from a centre at Seaton, th Mesozoic rocks exposed in the coastal region between Babbacombe an Burton Bradstock. About thirty-five members and friends attended th meeting, the secretarial side of which was very efficiently undertaken b Mr. A. J. Barber.

During the excursions use was made of the unpublished work of Dr D. J. C. Laming on the New Red Sandstone and of Dr. M. K. Howart on the Middle Lias. The Directors gratefully acknowledge their indebte ness to these workers.

Saturday, 20 August (Director, W. E. Smith)

Those members who had reached Seaton by the early afternoo assembled on the Esplanade and walked to the Beer Stone Quarries. Th first stop was made in the disused quarry on the south side of the Branscombe road (30/213894). Here the Director summarised the local tectonic and stratigraphical succession before discussing the petrology of the Bee Stone. The surface of the hard white quartziferous limestone which form the floor of the quarry was then examined. This surface is the erosion-plan which always forms the top of Jukes-Browne's Division B of the Cenomanian Limestone in South Devon. The trace of this erosion-plane is wel exposed in the vertical cliff-sections on the coast. It is only in this quarry however, that an extensive area of the surface is revealed in plan. Althoug the beds immediately above the erosion-plane were largely concealed b heaps of flint-nodules derived from the working quarry, small exposure were seen in the extreme western end of the pit, and were found to consis of soft chalk containing scattered grains of quartz and glauconite. Severa tests of *Conulus castanea* (Brongniart) were collected from this horizon This echinoid, although not restricted to the Turonian, is particular common in the lower part of the *Inoceramus labiatus* Zone (*Rhynchonell cuvieri* Zone) around Beer. Despite the poor exposures there would therefore appear to be no evidence of the presence of the very sandy bed terme

Division C of the Cenomanian Limestone by Jukes-Browne. Instead the beds immediately above the Cenomanian Limestone agree most closely with the basal part of the Middle Chalk exposed between Beer Beach and Beer Head. This is rather surprising since Division C is well developed in the Hooken Landslip to the south of the quarry and in a small sand-pit alongside Bovey Lane to the north.

The main quarry section exposes about twenty feet of shattered flintless chalk belonging to the *I. labiatus* Zone. Numerous examples of the index-fossil of this zone were found, especially in blocks derived from the so-called 'cockly' beds. No massive beds of freestone are exposed in the quarry although the chalk frequently has the gritty texture characteristic of the Beer Stone. Much of it is very nodular like the equivalent horizon in the cliffs around Beer Beach.

In the large working quarries on the opposite (north) side of the road the Director pointed out the lithological contrast between the two Middle Chalk zones which is shown at the entrance to the underground workings for Beer Stone. The numerous lines of flint-nodules in the uppermost or *Terebratulina lata* Zone came as a surprise to certain members who were more familiar with this horizon in the London area. A brief examination of the now disused underground workings was then made. Nowadays the comparatively small demand for the Beer Stone is met by cutting it from the floor of the quarry after the overlying chalk has been removed for lime-burning. In these open-cast workings members were able to see that the stone, when freshly exposed, is soft enough to be extracted and dressed with steel saws. Upon exposure and air-drying, however, the stone hardens considerably as can be seen in the new shelter overlooking Beer Beach.

Sunday, 21 August (Director, D. J. Shearman)

The party travelled by coach from Seaton to Torquay. A brief halt was made at Newton Abbot to enable the Director to describe the nature and origin of the Oligocene ball-clays and lignite exposed in the large clay-pit opposite the racecourse (20/862724). Lack of time prevented an examination of the exposure so the coach proceeded directly to the end of the metalled road overlooking Petit Tor Cove, Torquay (20/924663). On the beach below, the Director summarised the relationship between the various outcrops of New Red Sandstone in Devon and the folded rocks of the Cornubian massif. He then referred more specifically to the Torquay district and summarised the results of Dr. Laming's researches on the local breccias. Each member was provided with copies of the illuminating palaeogeographical panoramas that Dr. Laming had constructed from the results of his work.

Although the lower part of the cliff at Petit Tor Cove was obscured by extensive red mud-flows derived from the Watcombe Clay, a small exposure of these clays, apparently *in situ*, was seen at beach-level at the rear of the cove. The overlying red breccias (Maidencombe Breccias), which rest unconformably upon the Watcombe Clay, were seen to be banked up against the grey iron-stained Devonian limestones of Petit Tor. Several typical Devonian corals were collected from the blocks of limestone which are a characteristic constituent of the Maidencombe Breccias. Examples of imbrication (pebble-stacking) were also seen and enabled the Director to demonstrate how this structure can be used to determine the direction of transport of phenoclasts in rudaceous rocks.

The party then rejoined the coach which proceeded to Shaldon. After lunch the low state of the tide enabled members to examine the Teignmouth Breccias exposed at Ness Point (20/941719), south of the Teign estuary. The Director indicated the abundance of large blocks of quartz-porphyry which is a characteristic feature of these breccias. He also commented upon the scarcity of limestone phenoclasts such as occur in the Maidencombe Breccias and discussed the palaeogeographical implications of this fact. Several fragments of murchisonite, a flesh-coloured variety of orthoclase possessing a beautiful golden schiller, were collected from the cliff-face.

After examining these breccias members ascended the tunnel which has been cut through the cliff and rejoined the coach. Just before crossing the long bridge over the River Teign a brief halt was made at the new parish church of St. Peter's, where Dr. E. J. Beer demonstrated the wide variety of stones used in its construction. Of especial interest was the widespread use of Polyphant Stone, a bluish-grey serpentinised picrite, for both internal and external decoration.

The coach was then driven through Teignmouth to Dawlish. Here, only a brief examination of the red Dawlish Sands exposed by the side of the railway, north-east of the station, was possible. The Director gave a short summary of the results of Dr. Laming's work on the nature and origin of these sands. He also discussed whether (a) the rocks seen during the day were of similar age throughout, the sequence being indicative of the increasing distance from the old Cornubian highlands, or (b) the rocks formed a true stratigraphical sequence and decreased in age eastwards. It was decided that the truth probably lies somewhere between these two extremes. After this discussion the party returned directly to Seaton.

Monday, 22 August (morning) (Director, D. J. Shearman)

The party travelled by coach from Seaton to Budleigh Salterton and walked along the beach in a westerly direction. Upon reaching the exposure of the famous Budleigh Salterton pebble-beds the Director summarised current views on their origin and discussed the nature and provenance of the pebbles and the sandy matrix. He also indicated examples of imbrication and false-bedding in the pebble-beds. A wide variety of the ovoid quartzite pebbles which characterise the pebble-beds at their type-locality were collected. Many pebbles of tourmalinised grit, containing drusy cavities lined with acicular black crystals of black tourmaline (schorl), were also collected.

A short distance farther west the red cuboidal mudstones (marls), which form the uppermost division of the conventional Permian, were pointed out. These marls are very similar to the Triassic Keuper Marl seen around Seaton and are undoubtedly of the same origin. A short discussion was held on the relative importance of wind and water in the transportation and deposition of the New Red Sandstone marls.

On the way back to the promenade a brief examination was made of the red sands which overlie the Budleigh Salterton pebble-beds. To the immediate east of the exposure of the pebble-beds the sands exhibit particularly deep honeycomb weathering. At the eastern end of the promenade they contain an irregular network of concretionary calcareous sandstone, the form and arrangement of which indicate that their calcitic cement was deposited from water percolating down joint-fissures in the sands. The source of this calcite is not known; it may have been derived from Cretaceous deposits which formerly overlaid the New Red Sandstone in this part of Devon.

After the examination of these sands and sandstones, members travelled by coach to East Budleigh where lunch was taken.

Monday, 22 August (afternoon) (Director, W. E. Smith)

The afternoon was devoted to the study of the Cenomanian deposits exposed in the Wilmington and Membury outliers. Although these outliers are only about six miles apart they exhibit very different developments of the Cenomanian. The two exposures which were examined in detail served to demonstrate this contrast.

From East Budleigh the coach proceeded to Honiton which is situated on the Keuper Marl, in the valley of the River Otter. The main Axminster road was then followed on to the Upper Greensand which caps the steep Honiton Hill. The first stop was made at the large sand-pit situated on the south side of the road, nearly opposite the 'White Hart', at the western end of Wilmington (30/208999). Here, the Director summarised the geology of the Wilmington outlier which includes the westernmost *inland* occurrence of Chalk in England. The preservation of this small patch of Chalk is due to the westerly downthrow of an important N–S. fault which crosses the main road about half a mile east of the pit.

The beds exposed in the sand-pit have been described by Jukes-Browne (1903, p. 128), but further working has revealed a more complete succession. The major part of the working-face consists of at least twenty feet of coarse calcareous sands loose enough to be dug out by a mechanical excavator. The base of these sands remains unexposed, as in the days of Jukes-Browne. In the western part of the pit the sand passes up into a hard very fossiliferous sandstone ('grizzle'). This has an ill-defined base but averages about two feet in thickness. The grizzle is overlain by about eighteen inches of white limestone containing grains of quartz and glauconite which tend to be concentrated in irregular pockets. The base of this limestone is rather ill-defined although the upward lithological change from sandstone to limestone is rapid. In places the junction is rendered a little more conspicuous by the presence of sandstone pebbles in the upper part of the grizzle. Nevertheless, even when these pebbles are present, no sharply defined dividing-line can be seen. On the other hand, the top of the limestone is always sharply defined and is an erosion-surface similar to that seen in the Beer quarry. The erosion-surface is overlain by eight inches of rubbly or nodular chalk which is in turn overlain by two feet, or more, of gritty-textured chalk containing *Inoceramus labiatus* (Schlotheim). The beds above the erosion-surface are therefore the basal part of the Middle Chalk. The gritty texture of the beds recalls that of the Beer Stone, worked about six miles to the south. It is therefore significant that a freestone, known as Sutton Stone, was formerly obtained from excavations into the Wilmington outlier, near Sutton Barton.

The Middle Chalk in the sand-pit is overlain by typical brown 'clay with flints' which descends into steep-sided tapering pipes. In addition to these pipes the section exposes several rubble-filled fissures which have greatly hindered the extraction of sand in the south-western part of the pit. These fissures are two feet or more across and are filled with a jumble of large and small blocks of grizzle, quartziferous limestone and Middle Chalk. They may represent gulls connected with the cambering of the massive grizzle, etc., over the underlying unconsolidated Cenomanian sands.

A large collection of fossils was made from the masses of calcareous sandstone rejected during the screening of the sands and from the large blocks of grizzle, etc., removed as overburden. Some of the fossils, especially the shells of oysters and scallops, were found to be partially silicified. In most cases the replacement took the form of mutually interfering rings of white or pinkish beekite. Among the fossils collected were ammonites belonging to the typical Cenomanian genera: *Mantelliceras*, *Calycoceras* and *Schloenbachia*. Other fossils included: *Cyclothyris difformis* (Lamarck), *C. compressa* (Lamarck), *Pecten* (*Aequipecten*) *asper* Lamarck, *Neithea quinquecostata* (J. Sowerby), *Inoceramus etheridgei* Woods, and numerous echinoids, among which *Holaster* was especially conspicuous. The *Inoceramus* has been identified by Dr. L. R. Cox who regards it as the same as that recorded by Jukes-Browne (1903, p. 129) as '*I. striatus* Sow.'.

After collecting from this remarkably rich fauna the party rejoined the coach which proceeded to Membury. As at Wilmington the Chalk at Membury owes its preservation to the westerly downthrow of an important N–S. fault. This fault passes just east of Membury village and brings up the Rhaetic and Lower Lias on its eastern side. In a broken-down wall in the village members were able to examine blocks of Blue Lias limestone containing numerous small examples of *Plagiostoma gigantea* (J. Sowerby). These blocks presumably came from the old Tolcis quarry near Membury.

After passing through Membury village the coach climbed the very narrow Furley Lane as far as the Devon Trading Company's new chalk-pit (31/276042). The Chalk exposed in this pit underlies Middle Chalk of the *I. labiatus* Zone which caps the hill between Membury and Furley. The exposed working-face consists of over thirty feet of cream-coloured and white, soft, well-bedded chalk. Macro-fossils are extremely rare apart from occasional fragmentary shells of *Inoceramus*. A few rows of irregular siliceous nodules occur as the lower part of the pit. The nodules are usually white in colour and have a porcellanous texture so that they are not conspicuous when *in situ*. These peculiar 'flints' serve to link the deposit with the Lower Chalk of South and West Dorset.

The basal part of the Chalk is very poorly exposed but a small thickness of glauconitic chalk was seen near the entrance to the pit and a small trial-hole by the side of the rails leading to the working-face of the quarry exposed the basement-bed. In the latter exposure the Chalk can be seen to become increasingly sandy and glauconitic downwards. The basement-bed is about ten inches thick and rests upon a green-stained erosion-surface cut across the calcareous grit which forms the conventional top of the Upper Greensand. The bed contains numerous green and brown stained pebbles of sandy limestone set in a matrix of slightly sandy limestone containing comparatively little glauconite. Although most of the pebbles show some evidence of phosphatisation it is only at about three inches above the base, and higher, that phosphatisation is really intense.

Mr. J. M. Hancock, who had collected from the trial-hole soon after it had been dug, commented upon the ammonite faunas and contributes the following note:

> In the lower part of the conglomerate ammonites are preserved as casts in green-stained sandy limestone. At higher levels they are preserved as phosphatic casts. These distinctive modes of preservation according to horizon, enable any ammonites collected from loose blocks to be assigned to one of two levels. The ammonites from the basal few inches include *Mantelliceras* spp., e.g., *M. hyatti* Spath; *Hyphoplites* spp., e.g., *H. curvatus* (Mantell); *Schloenbachia* spp., e.g. *S. subtuberculata* (Sharpe). This is a Lower Cenomanian assemblage such as occurs in Division A of the Cenomanian Limestone in the coastal sections between Lyme Regis and Sidmouth.

> The ammonites preserved as phosphatic casts, i.e. those from the upper part of the conglomerate, include: *Scaphites æqualis* J. Sowerby (abundant); *Turrilites costatus* Lamarck; *Acanthoceras* aff. *hippocastanum* (J. de C. Sowerby); *Protacanthoceras* sp. nov.; *Calycoceras gentoni* (Brongniart) and a wide range of other *Calycoceras* spp.
>
> This is a Middle Cenomanian assemblage comparable to that of the Chalk basement-bed on the South Dorset coast (e.g. Ringstead) and as occurs at Snowdon Hill, Chard.
>
> The occurrence of Lower and Middle Cenomanian ammonites in the basement-bed at Membury, although not actually at the same level, probably explains the otherwise anomalous records of similar associations elsewhere.

The Director then contrasted the two exposures which had been examined. In passing six miles to the north-east of Wilmington the thick Cenomanian sands had thinned out altogether. Only a few inches of the basement-bed at Membury had any resemblance with the Cenomanian Limestone. At the same time there were apparently some fifty feet of poorly fossiliferous chalk beneath the *I. labiatus* Zone. The scarcity of fossils renders the dating of this chalk very difficult but it would appear to be younger than the main divisions of the Cenomanian Limestone. In other words, except for a few inches of the basement-bed the great thickness of Lower Chalk at Membury is not represented at Wilmington. This indicates that the stratigraphical break between the quartziferous limestone and Middle Chalk at the latter place is of considerable importance.

After collecting many of the characteristic fossils from the small, but productive, trial-hole the party returned to Seaton via Axminster and the valley of the River Axe.

Tuesday, 23 August (Director, W. E. Smith)

The party assembled on the Seaton esplanade and walked westwards along the shingle, past red cliffs of Keuper Marl, to Seaton Hole. Vertical displacement of some of the green bands in the marls served to demonstrate the presence of small-scale faulting while, just east of Seaton Hole, they revealed a low faulted anticline. At Seaton Hole the Keuper Marl was seen in contact with Cretaceous rocks exposed on the western or downthrow side of a conspicuous fault. The Director summarised the Cretaceous succession seen in strike-section along the western side of the fault-gully and in the westerly dipping section in Whitecliff. Because of this westerly dip the section between Seaton Hole and the eastern side of Beer Beach provides the most complete accessible succession of Cretaceous rocks in South Devon. The party examined the numerous large blocks on the foreshore under Whitecliff and collected fossils from the Chert Beds, the Cenomanian Limestone and the nodular chalk of the *I. labiatus* Zone.

The party then ascended the zigzag path leading up the fault-gully and walked across the top of the Whitecliff to Beer Harbour. With the aid of diagrams adapted from those of Rowe (1903) the geological structure and succession on each side of the beach was explained. On the northern side the prominent flintless marly bands in the otherwise flinty *T. lata* Zone were pointed out. These bands can be traced all round the Beer cliffs and serve as valuable datum planes in inaccessible cliff-sections. The prominent air-weathered bluff known as Annis' Knob was next considered and the junction between the uppermost Turonian (*Holaster planus* Zone) and the lowermost Senonian (*Micraster cor-testudinarium* Zone) was demonstrated. This latter zone has been largely stripped away by erosion in South Devon, Annis' Knob providing the most accessible section in that which still remains. The peculiar lithology of the chalk exposed in the bluff was then discussed (Rowe, 1903; Smith, 1957).

Turning to the west the Director first indicated the conspicuous conical embayments in the cliff just north of the cave-riddled point known as The Hall. These can be described as sectioned solution-pipes from which the 'clay with flints' has been washed out. The stratigraphical succession exposed in the cliffs between the beach and The Hall was then summarised.

After a short discussion the party descended on to the crowded beach in order to examine the Cenomanian Limestone exposed on the western side. The main exposure studied was that on the northern side of the small easterly projecting point which separates Beer Beach from a very small cove to the immediate south. The high tide prevented an examination of the interesting section exposed around this cove. Nevertheless, members were able to see the flagrant unconformity between the Cenomanian Limestone and the uppermost beds of the Upper Greensand. The Director demonstrated that the Cenomanian Limestone and the lower part of the *I. labiatus* Zone become progressively thinner as they are traced towards the eastern end of the point. Members were also shown the penetration of Cenomanian sediments into fissures and crevices in the top of the Upper Greensand (Smith, 1957).

The party then walked to the Beer Head coastguard station, via the cliff path over Arratt's Hill. In summarising the geology of the Hooken cliffs and undercliff particular stress was laid upon the great thickness of Cenomanian deposits in the vicinity of the old Beer Stone adit and in the slipped blocks known as the Pinnacles. Near the adit the Cenomanian has a total thickness of nearly thirty feet, a great contrast with the small thickness seen around Beer Beach.

After lunch the party descended the narrow landslip path on to Hooken Beach where the Director indicated the remarkable westerly attenuation of the Cretaceous rocks in the Branscombe end of the landslip. The nodular *I. labiatus* chalk was seen to thin out gradually until, opposite the ivy-covered Mitchell's Rock, the flinty *T. lata* chalk was seen to rest within a few feet of the Upper Greensand. This remarkable attenuation and overlap suggests that another region of intra-Cretaceous uplift occupied the site of the Branscombe Mouth Gap. Significantly the *I. labiatus* chalk reappears in the cliffs on the western side of this gap. It would seem, therefore, that the Cenomanian reaches its greatest thickness between two regions of intra-Cretaceous uplift.

Most of the party then walked eastwards along the shingle beach. An enormous foundered block beneath the Pinnacles provided a convenient section in which to study the thick Cenomanian deposits previously seen in the poorly accessible Hooken cliffs. Beneath chalk of the *I. labiatus* Zone members were able to examine Division C of the Cenomanian Limestone, a bed of very local distribution (Smith, 1957). In the foundered block it is about four feet thick and consists of comparatively soft chalk containing abundant sand and glauconite. The base of the bed rests upon an erosion-surface cut across a layer of phosphatised limestone pebbles which forms the top of Division B. On the other hand, it passes upwards without a break into the Middle Chalk, a feature which shows that it is of very late Cenomanian age. Several specimens of *Orbirhynchia wiesti* (Quenstedt), a rhynchonellid very close to *Orbirhynchia* [*Rhynchonella*] *cuvieri* (d'Orbigny), were collected from the bed. Phosphatised fossils derived from earlier Cenomanian deposits were also found, particularly in the lower part. These clearly indicate that such deposits were being eroded during the accumulation of Division C, which therefore has a 'mixed fauna'. The base of the Cenomanian Limestone in the large foundered block could not be examined since it was buried beneath shingle. The basal part of the Cenomanian was, however, seen a short distance to the east in several smaller fallen blocks. Some of these blocks contain about twelve feet of Division A, the lower part of which contains abundant quartz grains and small pebbles together with large branching polyzoa. The latter have been identified as *Ceriopora ramulosa* Michelin by Dr. Dighton Thomas who states that they are the largest polyzoa found in British rocks. These beach-blocks are also interesting in that they demonstrate the restricted distribution of Division C. Despite the presence of this bed in the huge block beneath the Pinnacles, it is completely absent in those more easterly blocks, the basal *I. labiatus* chalk resting directly on Division B (Smith, 1957).

The Director next described the Little Beach section stretching eastwards towards the point at Beer Head. The lowest beds seen are the greenish Foxmould sands which contain hard concretionary 'burrs' often rich in the spirally coiled annelid, *Serpula concava* J. Sowerby. The general dip is easterly so that successively higher horizons can be studied as Beer Head is approached. The section is dominated by a fine air-weathered cliff-face about two hundred feet high which shows a continuous, but largely inaccessible, vertical section extending from the Upper Greensand to the *M. cor-testudinarium* Zone of the Upper Chalk. The Cenomanian Limestone in this section is inaccessible, deeply weathered and superficially decalcified but is undoubtedly much thinner than in the Hooken Landslip and beach blocks, its *total* thickness being not more than seven feet.

At the eastern end of the section an enormous fallen block, large enough to hold the whole party, gave easy access to the thick Cenomanian deposits around Beer Head. The junction between the calcareous grit which forms the top of the Upper Greensand and the coarse basal part of Division A, was pointed out. This is not only an open divisional-plane but is rendered particularly conspicuous by the remarkable abundance of *Ceriopora* in the base of the Cenomanian deposits. A large collection of fossils was then made, especially from the lower part of the Cenomanian Limestone. The fauna from this horizon included many forms which had been seen in the calcareous sandstones at Wilmington.

After an early tea in Beer village about half the party travelled by boat to Pound's Pool Beach, just south of The Hall. Here, the Director demonstrated the attenuation of the Cenomanian Limestone and the *I. labiatus* Zone as they are traced from The Hall westwards, towards the rear of the beach (Smith, 1957).

After collecting fossils from the air-weathered Cenomanian Limestone exposed in this rarely visited section, the group returned to Seaton by boat.

Wednesday, 24 August (Director, W. E. Smith)

The party assembled on the Seaton esplanade and walked eastwards towards Haven Cliff. From the bridge over the Axe the Director pointed out and explained the easterly diversion of the river mouth by a high shingle ridge. The geological succession in Haven Cliff was summarised and the unconformity between the Keuper Marl and the Cretaceous rocks stressed. The route then lay up the steep lane leading to the Axecliff golf-course and along the public footpath leading to the edge of the Bindon landslip. The Lyme Regis footpath through the densely wooded undercliff was followed as far as a small side-track leading to the shore at Culverhole Point. Looking westwards the upward passage of the red Keuper Marl into the Tea Green Marl could be plainly seen. On the eastern side of the Culverhole gully a clear but somewhat degraded section in the Rhaetic Beds was examined. The eroded surface of the Tea Green Marl was found between the beach boulders at the foot of the section. The overlying Rhaetic Bone-bed was poorly exposed but yielded many fish remains and a fine reptilian tooth. The pyritic *Pteria contorta* shales were found to be deeply weathered and full of minute glistening selenite crystals. Nevertheless some of the lamellibranchs which characterise this horizon were found, e.g. *Pteria contorta* (Portlock) and *Protocardia rhaetica* (Mérian). The Cotham

Beds yielded little of interest but a band full of lamellibranch casts was discovered in the overlying White Lias. This band also yielded several casts of a solitary coral which have been identified as *Oppelismilia* by Dr. Dighton Thomas. This record is of especial interest since corals are rare in the Rhaetic rocks of Britain. Furthermore, they must be almost the earliest hexacorals in the British stratigraphical column. The only earlier example known to the writer is the *Heterastraea* found by Richardson in the *Pteria contorta* shales of the Severn Valley (Tomes, 1903).[1]

The Director next indicated the unconformity at the base of the Albian rocks which can be seen resting directly upon the White Lias. The eastern side of the Culverhole Gap provides the only accessible section of these basal beds in the Seaton district. They are also shown in a large fallen block of White Lias which has carried down a small thickness of the overlying Cretaceous. The basal Albian consists of black sandy clay containing small scattered pebbles of quartz and fragments of White Lias limestone. Several crushed brachiopods, which appear to be undescribed zeillerids, were collected from this horizon by Mr. E. F. Owen.

The easterly traverse was then resumed over large blocks of Upper Greensand. These contain numerous oyster shells showing various stages in beekitisation. They also contain several pebble-beds consisting of bored, ovoid sandstone pebbles and drifted shell-fragments. There is no doubt that these pebble-beds resulted from the penecontemporaneous erosion of nearby Albian deposits which may have been due to intra-Cretaceous earth movements (Smith, 1957).

The magnificent sections of Foxmould and Chert Beds in the huge slipped masses in front of the Dowlands Landslip were next examined. A halt for lunch was made beneath the dilapidated Rock (Cliff) Cottage.

On the shore beneath the cottage a magnificent exposure of typical Blue Lias is exposed in a low dissected plunging anticline or pericline, the limestones being particularly well displayed in broad arcuate reefs. The surfaces of several of the lower limestones are covered with large sectioned coroniceratid ammonites showing that the exposed beds lie within the upper part of the Blue Lias. On the western side of the anticline part of the skeleton of a plesiosaur was found in a shingle-covered reef. After this had been examined and photographed it was re-covered with pebbles in the hope that it would thereby escape the attention of irresponsible collectors.

The coastal traverse was then continued past slipped masses of Upper Greensand and Chalk to Charton Bay. At the western end of this bay the junction between the White Lias and the Pre-*planorbis* Beds of the Blue Lias was seen in a large foundered block. The Rhaetic Bone-bed, which can occasionally be seen at sea-level near this block, was unfortunately completely obscured by boulders and shingle. Under Rock Cottage the upper part of the Blue Lias can be seen at sea-level; the appearance of Rhaetic Beds at this level farther east therefore suggests an approach to another anticline in Charton Bay. The back of the bay itself, however, exposes almost the whole of the Tea Green Marls overlain by Rhaetic and Blue Lias. The Director suggested that the comparative suddenness with which these marls appear was due to faulting. The presumed fault, like all the important faults in the area, would have an easterly upthrow. Unfortunately the extensive landslipping and boulder-strewn shore in the critical region makes it impossible to produce unequivocal evidence of faulting.

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[1] A specimen has been presented to the British Museum (Natural History) and registered as R.40970.

A few members of the party accompanied Dr. Ager to Pinhay and Lyme Regis in order to examine the classic section of Rhaetic and Blue Lias exposed between these localities. The remainder examined the numerous large blocks of Cretaceous rocks which litter the shore at Humble Point, on the eastern end of Charton Bay. One of these shows the complete succession from Upper Greensand to Middle Chalk with all three divisions of the Cenomanian Limestone represented. The lowermost or shelly Division A rests abruptly upon the blocky calcareous grit which forms the top of the Upper Greensand. Nevertheless, in places, its lower part, containing *Ceriopora ramulosa* Michelin, fills angular 'pipes' which descend for nearly a foot into the grit. The top of Division B consists of numerous large, brown, heavily-phosphatised pebbles of limestone which project from the surface of a heavily phosphatised crust. This accumulation of phosphatised pebbles is overlain by soft sandy glauconitic chalk (Division C) which descends into crevices between the pebbles. As in the Hooken Landslip this division contains abundant brachiopods such as *Orbirhynchia wiesti* (Quenstedt) and passes up into flintless Middle Chalk of the *I. labiatus* Zone.

A rich fauna of phosphatic casts of ammonites was collected from the pebble-bed at the top of Division B. Most of them came from a large block a few yards to the east of that described above and in which the phosphatised pebble-bed is exposed in plan with large patches of Division C still adhering to it. The cephalopods which were collected from the pebble-bed include *Eutrephoceras* sp., *Schloenbachia falcatocarinata* (Schlüter), *S.* aff. *lymensis* Spath, *S.?* aff. *subvarians* Spath, *Calycoceras* cf. *planecostata* (Kossmat), *C. gentoni* (Brongniart ex. Defrance M.S.), *Eucalycoceras* sp. nov., *Acanthoceras hippocastanum* (J. de C. Sowerby), *Protacanthoceras compressum* (Jukes-Browne), *Euomphaloceras euomphalum* (Sharpe), and abundant *Scaphites æqualis* J. Sowerby.

The party then took the path leading up from the beach to the footpath through the landslip. The Director indicated the point at the extreme end of Charton Cliff, on the eastern side of the track leading up to Charton Farm, where the Cenomanian Limestone is absent. At this point the Upper

Greensand is overlain directly by slightly sandy, glauconitic Middle Chalk. The rapid thinning out of the Cenomanian in the Charton cliffs suggests that an area of intra-Cretaceous uplift occupied the site of the Charton Valley. It is significant that in the two main areas where the very sandy Division C is developed, i.e. in the Hooken Landslip and at Humble Point, there is evidence of nearby intra-Cretaceous uplift. The abundance of sand in this division appears to be due to the local exposure of the Upper Greensand and sandy Cenomanian deposits to marine erosion during late Cenomanian and early Turonian times.

The return journey to Seaton was made via the picturesque undulating footpath through the landslip.

Thursday, 25 August (Directors, D. V. Ager and W. E. Smith)

The party travelled by coach to Lyme Regis where a brief halt was made so that members could visit the museum. A few members, including the President, visited the famous Church Cliffs section in the Blue Lias, now fast disappearing beneath concrete coastal defences. The coach was taken up the Charmouth road as far as the public footpath leading over Black Ven to Charmouth. At a convenient point on this path Dr. Ager summarised the local Jurassic stratigraphy. The thick vegetation prevented any detailed examination of the Cretaceous rocks though a fine section in the yellowish Foxmould was seen in the slump-scarp overlooking the path. The disturbed nature of the overlying Chert Beds was ascribed to the washing-out of sand by water percolating between the masses of chert. The path was then followed into Charmouth village where an early lunch was taken.

After lunch the party assembled on Charmouth beach where they were met by Dr. W. D. Lang and Mr. J. F. Jackson. Dr. Lang indicated the contortions in the Black Ven Marls and described the sharp folds forming the Mouth Rocks. He discussed the origin of the contortions and folds, stating that they were now held to be due to valley-bulging between the high ground which now terminates in the Black Ven and Stonebarrow cliffs.

The party then walked eastwards along the beach towards Seatown, under the guidance of Dr. Ager. He first indicated the main subdivisions of the Black Ven Marls which yielded many characteristic fossils. Farther east, the Belemnite Marls were examined as they descended to beach-level. Many beautiful pyritised ammonites were collected from parts of the beach where waves had concentrated the heavy pyritic material derived from these beds. Just past the Ridgewater Waterfall the effect of several step-faults, each with easterly downthrow, was explained. The face of the easternmost fault was exposed as a fault-line scarp since the Green

Ammonite Beds on the downthrow side had been denuded more rapidly than the Belemnite Marls.

The Green Ammonite Beds on both sides of St. Gabriel's Mouth were largely obscured by extensive sun-baked mud-flows. Nevertheless, a few fragmentary ammonites such as *Androgynoceras* were collected. At this point Dr. Ager summarised the succession exposed on the precipitous Wear Cliff beneath Golden Cap. The position of the Three Tiers, the lowest of which forms the conventional base of the Middle Lias, was indicated. Wave-worn blocks of these laminated micaceous sandstones were abundant on the shore beneath Wear Cliff but yielded very few fossils.

Between Wear Cliff and Seatown the upper part of the Belemnite Marls were seen in the core of a low anticline. The Belemnite Stone, a thin but persistent nodular limestone, which is taken as the top of the Belemnite Marls, was better exposed here than farther east and yielded a rich fauna.

At Seatown the succession in the cliffs to the east of the Gap was summarised and the effects of the Seatown Fault thereby demonstrated. After tea at the Anchor Hotel the coach was rejoined and the party returned to Seaton via Chideock and the main coast road.

Friday, 26 August (Director, D. V. Ager)

The party travelled by coach to Burton Bradstock and walked to the Cliff Hill road-cutting. This exposes about twenty-five feet of the topmost Bridport Sands, overlain by about twelve feet of Inferior Oolite limestones. Despite the small thickness of these limestones all three subdivisions of the Inferior Oolite are represented, although they are separated by important non-sequences. The top of each of the two lower subdivisions is an erosion-plane overlain by a thin conglomeratic bed. These conglomerates contain limestone pebbles and rolled fossils derived from many of the missing sub-zones. Dr. Ager contrasted this highly condensed sequence with the great thickness of the equivalent strata in the Cotswolds. Several sharp-ventered compressed ammonites assignable to the Aalenian genus, *Lioceras*, were collected from the sandstone 'burrs' in the Bridport Sands. The Vensulian limestones yielded a rich fauna which included many globose terebratulids of the *Sphaeroidothyris* group and the typical ammonite, *Parkinsonia*.

From the top of Burton Cliff the Isle of Portland could be plainly seen. Opportunity was therefore taken to discuss the nature and origin of the famous Chesil Bank which stretches from West Bay to Chesilton. Upon descending to the beach members were able to see the well-graded nature of the fine shingle which characterises the north-western end of the bank.

The degraded cliffs to the south-east which consist of down-faulted Forest Marble and Fuller's Earth were not examined. Instead, the party walked north-westwards along the beach under the precipitous Burton

Cliff. This exposes over a hundred feet of Bridport Sands capped by the thin Inferior Oolite limestones and a small thickness of the basal Fuller’s Earth clays. The frequent repetition of moniliform layers and nodular masses of calcareous sandstone excited much comment. Near the western end of the cliff the detailed succession given by Richardson (1927, p. 60) was easily recognised in the huge fallen blocks which litter the shore. After collecting many of the characteristic fossils from these blocks, the party rejoined the coach at Burton Bradstock and drove into West Bay for lunch.

After lunch the westerly traverse along the beach was continued, past the slipped and disturbed Fuller’s Earth clays exposed in Watton Cliff. Numerous large blocks of shell-fragment limestone derived from the overlying Forest Marble were seen on the shore near the western end of this cliff and yielded several ossicles of the ‘pear-encrinite’, *Apiocrinus*.

On reaching the re-entrant in the cliff about one third of a mile east of Eype Mouth, Dr. Ager pointed out the fault by which the Great Oolite Series is let down against the Middle and Upper Lias. On the seaward side of the fault, the Fuller’s Earth was seen overlain by the Forest Marble. Specimens of *Goniorhynchia* cf. *boueti* (Davidson) on the scree, indicated the presence of the ‘*boueti* Bed’ at the top of the Fuller’s Earth. Loose blocks of grey limestone at the foot of the cliff yielded numerous specimens of *Wattonithyris wattonensis* Muir-Wood and *Rhynchonelloidella wattonensis* Muir-Wood, and were attributable to the ‘*Wattonensis* Bed’ of the Fuller’s Earth. Dr. L. R. Cox found a loose solitary coral, *Montlivaltia slatteri* Tomes, apparently derived from the Upper Fuller’s Earth, a new record for the locality.

Some members of the party climbed up to the fault-plane and examined the Liassic rocks. The Director pointed out that the ‘Junction Bed’ at the base of the Upper Lias in Watton Cliff contains no representative of the *spinatum* Zone. Pre-Toarcian erosion here removed both the equivalent of the Marlstone Rock-bed and a considerable thickness of the Thorncombe Sands below, including the ‘*Thorncombiensis* Bed’ that was to be seen later on Thorncombe Beacon.

The party then moved on westwards, noting on the way that the fault-plane lies almost parallel to the coast. After passing Eype Mouth, the party began to examine the Middle Lias succession, which is so wel displayed in the cliffs that culminate in Thorncombe Beacon. Dr. Ager outlined the new observations about ammonite distributions recently made by Dr. M. K. Howarth, notably the inclusion of the Thorncombe Sands in the *margaritatus* Zone, and the recognition of three sub-zones within that zone. He also summarised his own observations on the distribution o species of *Gibbirhynchia* (Ager, 1954).

The Eype Clay, at the bottom of the Middle Lias succession, is wel exposed in the low cliff just west of Eype Mouth. In it, the 'Eype Nodule Bed' was seen about eight to ten feet above the beach, and from this the party collected many fossils including a rare ammonite of Upper Lias aspect attributed by Dr. Howarth to *Leptaleoceras pseudoradians* (Reynès) and an uncommon brachiopod *Gibbirhynchia amalthei* (Quenstedt).

Farther west, the party spent some time examining fallen blocks from several horizons. Among these were large masses of fine micaceous sandstone from the 'Starfish Bed' at the top of the Eype Clay which yielded fragmentary specimens of *Ophioderma*. Large calcareous doggers containing many specimens of *Gibbirhynchia muirwoodae* Ager were also seen. This species has been described by the Director (op. cit.) as coming from the Down Cliff Sands, but Dr. Howarth, in his more detailed study of this difficult cliff, has found it more common in the lower part of the Thorncombe Sands above. Of especial interest were the boulders of multicoloured, conglomeratic rock that had fallen from the 'Junction Bed' high in the cliff. This bed contains within its three to five feet the equivalents of about three hundred feet of strata on the Yorkshire coast, including representatives of the Domerian, Whitbian and Yeovilian. Several breaks in deposition were noted in the loose blocks and the Director drew members' attention to the foot or so of ferruginous limestone present on certain blocks, which represents the Marlstone Rock-bed. He also discussed the interesting fauna of a thin bed seen in places above the Marlstone. This was called the '*Paltus* (*serrata*) Layer' by S. S. Buckman and J. F. Jackson, since it is characterised particularly by the Harpoceratid ammonite *Paltarpites paltus* S. S. Buckman and the brachiopod *Prionorhynchia serrata* (J. de C. Sowerby). It also yields *Pleuroceras spinatum* (Bruguière) and appears to be referable to the zone of that ammonite. The brachiopod fauna is particularly interesting. *Prionorhynchia* is a common rhynchonellid genus in the Lias of southern Europe, but only appears in the British succession in the '*Paltus* Layer'. With it are other forms of southern affinities, notably a sulcate (i.e. inverted) terebratulid and a rhynchonellid, flattened along the anterior commissure, that belongs to Gregorio's genus *Cirpa*, a form best known in the Lias of Sicily and not previously recorded in this country.

A few of the more energetic members of the party climbed up to see the 'Junction Bed' *in situ* on the east face of Thorncombe Beacon. It was noted that the Thorncombe Sands are here perceptibly thicker than where they had previously been seen in Watton Cliff. They also include at their top, the '*Thorncombiensis* Bed', an indurated layer packed with *Gibbirhynchia thorncombiensis* (S. S. Buckman) which farther east has been removed by pre-Toarcian erosion. Above the sands, the Middle Lias is further represented by about eight feet of poorly fossiliferous clay, and up to eighteen inches of Marlstone Rock-bed. The party then returned to Eype Mouth for tea.

After tea the coach was rejoined in Eype village where the President moved the customary vote of thanks to the Directors and Secretary. The coach then returned direct to Seaton.

Saturday, 27 August (Director, W. E. Smith)

About twelve members travelled by private cars to the old quarry at the head of Smallacombe Goyle on the east side of Little Haldon. Unfortunately this famous section in the Upper Greensand was found to be badly overgrown, only a few small exposures being still visible. One of these, near the top of the section, revealed yellowish sands containing large masses of chert which proved to be very fossiliferous and yielded many silicified lamellibranch shells. Of especial interest, however, was the abundance of the large disc-shaped foraminifera, *Orbitolina concava* (Lamarck). Examples were found which were nearly three-quarters of an inch in diameter, an unusually large size for British Mesozoic foraminifera.

On the way back to Axminster Station a brief halt was made at Hutchin's quarry on the northern side of Wilmington village. A very fossiliferous bed which appeared to form the base of the Wilmington Sands yielded a very rich fauna. Among the fossils collected were the following ammonites: *Forbesiceras largilliertianum* (d'Orbigny), *F.* sp. cf. *beaumontianum* (d'Orbigny), *Mantelliceras* spp. (*couloni* d'Orbigny group), *M.* sp. nov.?, Desmoceratidae? Gen. nov. sp. nov., this peculiar form has a suture recalling that of *Uhligella derancei* Casey from the base of the Upper Albian.

This interesting fauna is being studied by Mr. C. W. Wright to whom the writer is indebted for his identification of most of the ammonites quoted in this report.

REFERENCES

AGER, D. V. 1954. The Genus *Gibbirhynchia* in the British Domerian. *Proc. Geol. Ass., Lond.*, **65**, 25.

ARKELL, W. J. 1933. *The Jurassic System in Great Britain.* Oxford Univ. Press.

JUKES-BROWNE, A. J. 1903. The Cretaceous Rocks of Britain. II. The Lower and Middle Chalk of England. *Mem. geol. Surv. U.K.*

RICHARDSON, L. 1927. The Inferior Oolite and Contiguous Deposits of the Burton Bradstock–Broadwindsor District, Dorset. *Proc. Cotteswold Nat. Fld. Cl.*, **23**, 60.

ROWE, A. W. 1903. The Zones of the White Chalk of the English Coast. III. Devon. *Proc. Geol. Ass., Lond.*, **18**, 1–52.

SMITH, W. E. 1957. The Cenomanian Limestone of the Beer District, South Devon. *Proc. Geol. Ass., Lond.*, **68**, 115.

TOMES, R. F. 1903. Description of a species of *Heterastraea* from the Lower Rhaetic of Gloucestershire. *Quart. J. geol. Soc. Lond.*, **59**, 403–7.

Palaeobotanical Excursion to Kew Gardens

2 June 1956

Report by the Director: D. V. AGER

Received 9 November 1956

TWENTY-SIX members of the Association attended this excursion which was intended to demonstrate some of the living representatives of several different groups of fossil plants, with special reference to their present and past distribution.

The party assembled at the Victoria Gate on the east side of the gardens. In his introductory remarks, the Director emphasised the non-specialist nature of the excursion, which paralleled an undergraduate demonstration conducted each year with the intention of making students familiar with the plants referred to in lectures.

The party then proceeded in a northerly direction past the pond and stopped first at the mound of the 'Temple of Aeolus' (**1**)[1] to examine specimens of *Magnolia* which had unfortunately passed their flowering season. The Director referred to the long fossil record and former wide distribution of this genus. It is thought to be well represented in the earliest definite angiosperm floras—for example in the early Cretaceous of Greenland. In late Cretaceous and early Tertiary times, the Magnolias were much more widely distributed than they are at present. They are known in the Mull leaf beds (probably of Eocene age) and persisted in France as late as the Pliocene. At the present day they are generally restricted to latitudes south of about 30° N., though they have an extreme northerly range (as in Japan) of about 45° N.

The party then passed through the rock-garden (**2**) and noted the use there of Carboniferous Limestone (with excellent specimens of *Dibunophyllum*), Wealden Sandstone and Inferior Oolite. A clump of 'horsetails'—*Equisetum*—are to be seen in the swamp garden here and form a direct link with their much larger predecessors in the Upper Palaeozoic both in morphology and presumed habit. Here also were specimens of the 'royal' fern *Osmunda regalis*, a member of a family which has an almost continuous fossil record extending back to the Permian.

Near the north end of the rock-garden the party entered the 'T-range' of glasshouses (**3**) via the Sherman Hoyt Cactus House, where New Red Sandstone is displayed in a suitable desert setting. There was some discussion of the adaption of plants to arid environments, and the evidence o such in the fossil record (e.g. in the Hilton Plant Beds of the Vale of Eden) After passing through successively warmer temperatures the party came t the lily-pond in the centre of the house (**4**) where they observed the tw best specimens of cycads at present available in the gardens (during th temporary closing of the Palm House for repairs). These were male an female plants of *Stangeria paradoxa* showing the characteristic features o this small and geographically restricted group. Though the Mesozoic i popularly known as the 'Age of Cycads' it has long been realised that th vast majority of fossil plants of this type actually belong to a distinc group—the Bennettitales. Professor Harris has shown, however, that tru fossil cycads were in existence as far back as the Rhaetic.

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[1] Figures in bold type refer to the localities marked on Fig. 1.

Whilst in this part of the house, the Director drew the party's attentio to the large proportion of tropical plants which have entire (as opposed t dentate) leaves. This character can be used as a guide to the climat prevailing at the time of a certain leaf flora even though the plants themselves may not be identified. Thus W. N. Edwards has shown that in th famous early Eocene leaf flora of Alum Bay in the Isle of Wight, abou 86 per cent of the plants present have entire leaves—implying a tropical o sub-tropical climate. Another plant seen here was a specimen of *Cinnamo* which is another genus having a long fossil record.

As they left the 'T-range' by the west door, Dr. J. Sutton drew the party' attention to the 'Chalk garden' on a mound opposite (**5**). This was in augurated in 1944 and provides an excellent display of plants characteristi of the English Chalk outcrops.

The neighbouring Tropical Fern House was next visited (**6**). Of specia interest here were some large specimens of *Angiopteris hypoleuca*. Thi belongs to the family Marattiaceae which has a long fossil record. Genera such as *Psaronius* (of the Carboniferous and Permian) may belong here, bu the family is much better known from the Mesozoic, in which its genera ar world wide in distribution. At the present day the family is restricted to th tropics. Along one wall of this house the party saw a large number o species of *Selaginella* and *Lycopodium*, humble living representatives of th Lycopodiales—the club-mosses—which were so important as forest tree in the late Palaeozoic. The Director briefly discussed the decline of thi group (and the Articulatales, or horse-tails) during Mesozoic and Tertiar times.

To the left of the main entrance to the Tropical Fern House, the part examined the famous *Ginkgo biloba* or Maidenhair Tree, planted here i 1762 (**7**). Two smaller specimens grow nearby. This is what Darwin calle a 'living fossil', being the sole living member of an important group o plants that is very well represented in Mesozoic rocks, and has bee recorded (but without real evidence) as far back as the Devonian. I probably owes its survival in historic times to having been cultivated and perhaps preserved as a sacred tree in Chinese and Japanese temple gardens. The Director drew the party's attention to the considerable range in size and form of the highly characteristic leaves. This is an important point to remember in connection with fossil members of the Ginkgoales, since many species and even genera have been founded solely on leaf characters. The special interest in the order lies in the fact that during fertilisation, motile

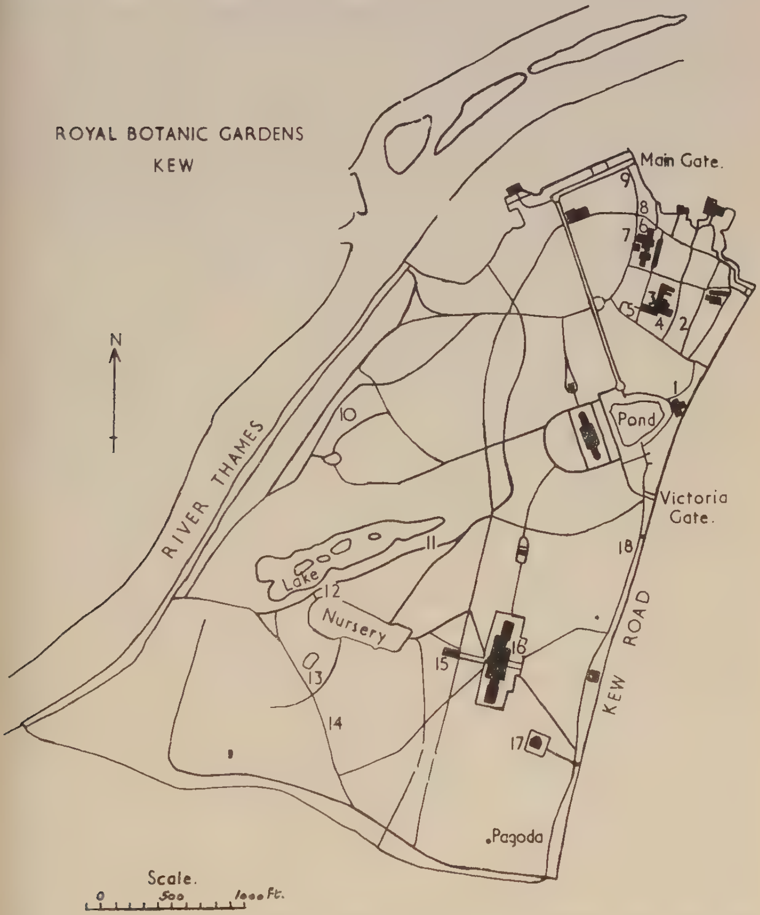

Fig. 1. Sketch-map of the Royal Botanic Gardens, Kew. Only the main paths are indicated, museums and glasshouses are shown in black. The figures refer to the localities mentioned in the text. This map is founded by permission on an official publication on sale in the gardens

antherozoids are liberated in the pollen tube. This is a primitive character, comparable to that seen in the Cycadales, and *Ginkgo* may be regarded as the most primitive of all living gymnosperms. In Mesozoic rocks, Ginkgoalean remains are generally more northerly in distribution than the Bennettitales, and throw some light on the climatic zoning of the time.

Next the party walked towards the main entrance, turning aside for a moment at the path-crossing to examine a specimen of the remarkable conifer *Metasequoia glyptostroboides* (**8**). This genus is closely related to the giant redwoods (*Sequoia*) of California, and both are well represented in Mesozoic and Tertiary rocks all over the northern hemisphere. *Metasequoia* was known as a fossil long before a small grove of living trees were discovered by Chinese botanists in Szechuan during the 1940s. It has recently been suggested that the honour of discovering this plant should go to an Irishman, Augustine Henry, who recorded it in China fifty years ago, but this claim has been disputed. The very restricted present-day range of the redwoods contrasts markedly with their former wide-spread distribution. It illustrates very well the dangers of too much theorising based on the present ephemeral record. A careless botanist might, for instance, postulate a drifting apart of North America and Asia merely on the evidence of present-day redwood distribution.

Near the Main Gate (**9**) the party was fortunate enough to see two large magnolias still retaining some of their flowers. This enabled the Director to demonstrate the supposedly primitive floral characters of this genus and its relations. The flowers are large, separate, bisexual, unspecialised and hypogynous, with numerous floral parts arranged in spirals (not whorls). The petals and sepals are free and distinct, and transitions are sometimes visible from sepals to petals and from petals to stamens. All these characters are regarded as primitive by most botanists and the family Magnoliaceae is commonly regarded as close to the ancestral stock of the angiosperms. The flowers also resemble quite closely those of certain members of the Bennettitales (Mesozoic so-called 'cycads'). Along with these morphological features of the living plants, there is the very important geological evidence of a fossil record extending back perhaps to the early Cretaceous.

The party then turned south-west and walked towards the river. They passed through 'Rhododendron Dell' (**10**) for no particular palaeobotanical reason, but because it happened to be in full flower at the time of the visit. They then walked round the north end of the lake to see the small grove of Araucarias (**11**). These were all the well-known 'Monkey Puzzle' of Victorian gardens (*Araucaria araucana*). Fossil conifers resembling this genus and its allies are known back to the Upper Trias and possibly in the late Palaeozoic. The family reached its maximum in the Jurassic with Araucarian cones, wood and leaves very abundant in terrestrial and inshore deposits all over the world. In the Tertiary rocks of the northern hemisphere, however, the family is much less common, though it did persist into the Eocene and Oligocene of Europe. At the present day it has a very discontinuous distribution in the southern hemisphere.

The party continued down the south-east side of the lake, and at the corner of the nurseries (**12**) the Director pointed out a group of low shrubs belonging to the genus *Ephedra*. This is one of three genera which constitute the interesting group Gnetales. This is placed provisionally with the gymnosperms, but their reproductive organs are closer to those of the angiosperms and have points in common with the Bennettitales. *Ephedra* itself has jointed stems rather like *Equisetum*, it is widely distributed in warm temperate regions of the northern hemisphere and is found in its natural state as far north as Brittany. From the considerable variation in habit of living members of the group, and the very wide scatter of the different species, the Gnetales are thought to be an ancient stock. Unfortunately their fossil record is very meagre and disputable, though they have been recorded as far back as the Jurassic. From their morphology one might expect the Gnetales to have formed a vital link in plant evolution. The Director suggested that if one interpreted plant history in the Churchillian manner, then one might say that if they did not actually happen, then they should have done!

Next the party cut across to the south-west end of the Lily Pond (**13**), where they saw another specimen of *Metasequoia*. In the pond is a fine specimen of the swamp cypress, *Taxodium distichum*, which has been recorded from various Tertiary deposits including the Oligocene of the Isle of Wight (where there is also a 'water lily bed') in an association of warm temperate plants, many of North American affinities. There are further specimens of *Ginkgo* in this vicinity, some of which appeared to have suffered from the recent hard winter.

A short distance farther along the path past the Water Lily Pond, the party came to a grove of redwoods (*Sequoia sempervirens*) from California (**14**), and they noted various points of resemblance to the much smaller specimens of *Metasequoia* already seen, in particular the very characteristic bark. A path on the left now led to Holly Walk, west of the Temperate House. A short visit was paid to the new Australian House (**15**), chiefly to see the only other cycad available in the gardens at the moment—a hidden specimen of *Macrozamia* still very small in spite of having been growing here for nine years.

The party now crossed Holly Walk to the Temperate House (**16**). Several plants were seen here that have already been discussed, including *Osmunda*, *Nymphaea* and *Magnolia*. Especial interest was taken in species of *Araucaria* quite different in superficial appearance from the familiar 'Monkey Puzzle', and in a number of tree ferns reminiscent of the late Palaeozoic floras.

The Temperate House was left by its southern door and the party moved across to the Refreshment Pavilion (**17**) for tea. After this they completed the circuit of the gardens to the Victoria Gate. The last halt of the afternoon was made by a fine specimen of *Liriodendron* just south of the 'Temple of Bellona' (**18**). This is another member of the Magnoliaceae, with distinctive leaves, which have been recorded as fossils from various localities in the Upper Cretaceous and Tertiary of Europe, America and the Arctic Regions. Even these apparently characteristic leaves may, however, be confused with those of the leguminous genus *Dalbergia*. Here Mr. T. Dewhurst, on behalf of the President, proposed a vote of thanks to Dr. and Mrs. Ager for the afternoon's demonstration, and this was approved by the assembled members.

In conclusion the writer would like to record his thanks to Sir Edward Salisbury, lately Director of the Royal Botanic Gardens, for permission to use the official map of the gardens as the basis for Fig. 1, and for other help in connection with this excursion.

A Clactonian Flint Industry at Little Thurrock, Grays, Essex

by J. WYMER

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ABSTRACT: A site, rich in artifacts of the Clactonian flint industry, exists at Little Thurrock, Grays, Essex. The industry is contained within a thin deposit of fluviatile gravel which is found at a height of forty-nine feet O.D. and is a fragment of an almost completely denuded terrace of the Thames. The relationship of this gravel deposit to the fossiliferous Grays' brickearth and the gravel to the north, which is mapped by the Geological Survey as Boyn Hill Gravel, has been examined and the flint industry considered in detail.

1. THE SITE AND METHOD OF EXCAVATION

THE SITE lies on the east side of the large quarry of the Globe Works, Whitehall Lane, Little Thurrock, Grays, Essex. The quarry is worked for chalk, the overlying Thanet Sand and Brickearth having been removed. At the northern end of the quarry is an exposure of four feet of sandy gravel capped by two feet of stony loam. This is mapped by the Geological Survey as Boyn Hill Gravel (Fig. 1). Just south of this gravel terrace there is a slope down to the present flood-plain of the River Thames. This slope, from a study of the adjoining land, appears to be continuous, but so much material has been removed from the district that this may not be so. None of the brickearth that covered this slope is now visible, but it was part of the spread from Grays to Little Thurrock (Hinton, 1900, 1907), which has now been almost totally removed for commercial purposes. The Geological Survey Memoir of the Dartford Area (Dewey, 1924) refers to the brickearth as consisting of 'bedded, fossiliferous sand and loam separated by a varying thickness of gravel from the chalk beneath. They (the spreads of brickearth) are banked more or less steeply against rising chalk to the north, which at its junction . . . is rubbly or decomposed, and at the southern margin are overlain by gravel of the flood-plain terrace.' The following section of the variable deposit is given:

Laminated clays or brickearth with thin seams of sand or gravel yielding mammalian remains and freshwater molluscs, followed by current-bedded sands	15 feet
Fluviatile gravel	10 feet

At the top of the rise from the flood-plain is three to five feet of well-bedded sandy gravel lying on the Thanet Sand. This gravel follows the eroded slope of the Thanet Sand and would appear to be referable to the lowest of the above deposits. King & Oakley (1936) note that the only implements from the deposits at Little Thurrock belong to a late stage of the Clactonian Industry. The recent excavations confirm the industry as Clactonian and assign the artifacts to the gravel overlying the Thanet Sand at the top of the steep rise from the flood-plain. There is some evidence that this gravel is part of a denuded terrace deposit which has been mostly washed into a channel subsequently aggraded with brickearth.

There is a small pit in this gravel deposit and my father remembered finding flint flakes in the scree of it when it was being worked in 1910.

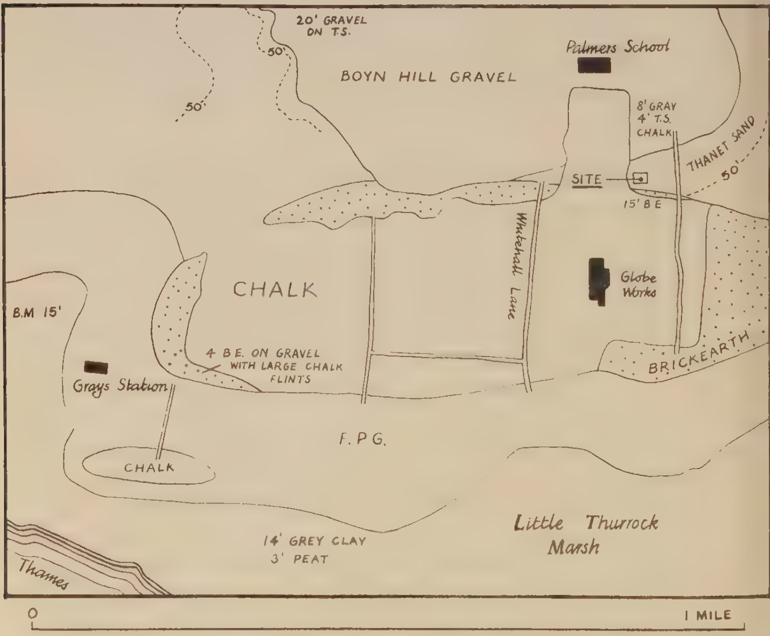


Fig. 1. Geology of Little Thurrock District, based on 6 in. Geological Survey map.

Three visits in 1949, 1950 and 1953 showed that the undisturbed gravel on the northern side of the pit was extremely rich in flint artifacts, with an average of about sixty to the yard. In September and October of 1954 three sections were cleared in the pit in an attempt to clarify the geology and confirm the industry contained in the gravel (see Fig. 3). Sections 2 and 3 on the northern side of the small pit were similar in stratification, but Section 1 on the opposite side, only a few yards away, was surprisingly different.

Vertical sections were dug with faces at right angles to each other, to the depth of the underlying Thanet Sand. Every piece of struck flint was collected and its vertical height recorded to the nearest six inches. No mammalian remains were found.

2. THE GEOLOGY

(a) Description of Sections

(*i*) *Section* 1 (Fig. 3)

A. Humus. Even thickness of nine to twelve inches suggests ploughing. Contained a few fragments of recent pottery, broken bricks and a flint scraper of Neolithic aspect. Comparison of level of ground with the surrounding land indicates that this is the original ground level, nothing having been removed during excavations for brickearth.

B. Brown, earthy sand with a few flints.

C. Clean, yellow sand.

D. Sandy gravel interspersed with seams of sand and pockets of tenacious, semi-iron-panned gravel. The sand seams are restricted to the lower half of this stratum and the semi-iron-panned pockets occur mainly in the upper half, tending to increase in size as the face of the excavation was taken back. A few flints occur in the seams of sand and in one such seam, eighteen inches above the base level, was a flake of marbled flint with secondary working along one edge (No. 33, Fig. 9) in almost mint condition. No artifacts were found in the semi-iron-panned masses.

The gravel is composed of sub-angular flints, pebbles and occasional nodules of 'Bullhead' flint. Three erratics were found of quartzitic sandstone, probably derived from the Lower Greensand.

E. A thin layer of grey and brown mottled clay with stones. This level was taken as a base for the recording of heights.

F. A very fine, powdery sand, similar in texture to the Thanet Sand, yet containing a thin seam of flints about four inches beneath the mottled clay. More isolated flints were struck one foot down in this sand, which was the base of the excavation.

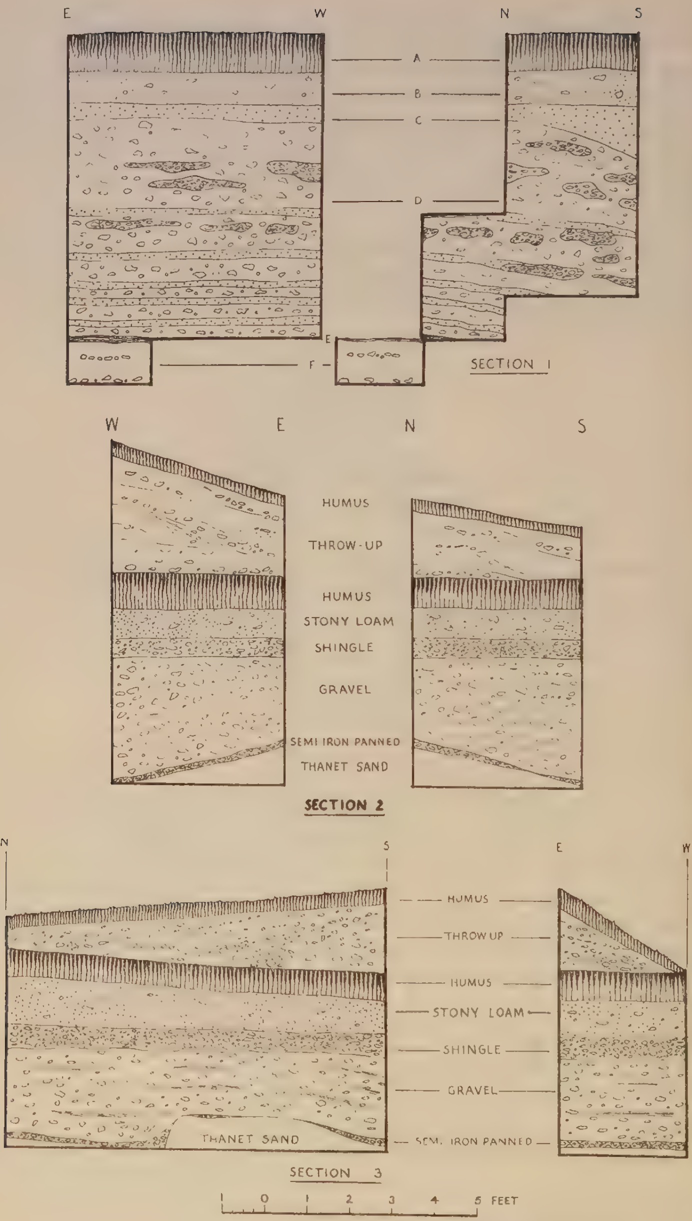


Fig. 3. Diagram showing lithology of sections described

(*ii*) *Section* 2 (Fig. 3)

This section had been partially cleared by an unknown person for garden gravel. It was completed and recorded, but was not extended because of the great amount of overburden; a throw-up presumably made by the gravel-diggers when removing the unwanted topsoil and stony loam.

The slope of the underlying Thanet Sand suggests a thinning-out of the deposit, but the undulations discovered in Section 3 show that it may be merely a local discrepancy in the floor. It is otherwise identical with that section, although at right angles to it.

(*iii*) *Section* 3 (Fig. 3)

A. Humus.
B. Throw-up.
C. Humus, top of which indicates original ground level.
D. Stony loam.
E. Shingle.
F. Gravel as in D of Section 1, but without the seams of sand and pockets of semi-iron-panned gravel. A few inconsistent, thin bands of ochrous staining which tend to follow the irregularities of the base.
G. A thin seam of semi-iron-panned gravel directly upon the
H. Thanet Sand.

(b) Distribution of the Artifacts

In Sections 2 and 3 the artifacts occurred at all levels between the very base (G) and the top of the shingle (E), although they were more prolific in the upper part, the base of the shingle being the richest area. They were in all conditions, from perfectly mint to very rolled, but the majority showed slight rolling.

The proportion of artifacts per yard in Section 1 was considerably less, only sixty-four flakes occurring in about three yards of gravel. Only two flakes (Nos. 22 and 33) were in a mint condition, the majority being slightly rolled and battered.

Summary of 64 flakes from Section 1:

Very rolled	2
Slightly rolled	47
Sharp	13
Mint	2

Summary of 158 flakes from Section 3:

Very rolled	—
Slightly rolled	77
Sharp	72
Mint	9

Apart from one rolled flake five inches long that was found in Section 1 (the size being taken from the bulb of percussion to the furthest distance only one other exceeded three inches. The similarity of the sizes of the flakes and the total absence of heavy cores suggests sorting by water action. No such thing was found in the other two sections. No artifacts occurred in levels B and C of Section 1, or below the mottled clay which was taken as the base level.

(c) Correlation with other nearby Pleistocene Deposits

The geological section, Fig. 2, was constructed from exposures dug and others already existing in the face of the quarry. Dotted lines indicate probable continuation of the strata. The solid black overlying both gravel deposits is a superficial covering of stony loam not necessarily having any relationship to either of them.

The higher terrace consists of six feet of loamy gravel, which thickens considerably to the west, on a bench at sixty-seven feet O.D. This is mapped by the Geological Survey as Boyn Hill Gravel. The lower terrace, in which the flint industry was found, has a bench level of only forty-nine feet O.D

It will be seen that only a very small area of the lower terrace escaped erosion. The point where the ochrous band of iron-stained sand commences to dip is the limit of the true terrace deposit. At this point the nature of the gravel changes; the sand content increases until it is very similar to the underlying Thanet Sand, but contains some gravel flints, and the base has a peculiar step in it. This sandy material shows no sign of bedding and may be the detritus from the erosion of the deeper channel in which the brickearth was subsequently aggraded. This break in the gravel explains the irregularities revealed in Section 1. The varying thickness of grave separating the chalk from the brickearth mentioned in the Geologica Survey Memoir would presumably contain much material derived from the gravel on the forty-nine feet O.D. level.

Fig. 2 shows the position of the now-removed brickearth and current-bedded sands, and also that they must be more recent than the grave containing the flint artifacts. The bench level is twenty-six feet below tha of the Lower Gravel at Swanscombe, only three miles distant, whicl contains a similar Clactonian Flint Industry, so it cannot belong to tha stage. If it be accepted that between the Lower and Middle Gravels a Swanscombe there was a period of marked erosion and subsequen aggradation, then the Little Thurrock gravel on the forty-nine feet leve appears to mark an interruption in the erosion during which this terrac was aggraded.

The Boyn Hill Gravel on a bench level of sixty-seven feet O.D. is mucl closer to the Lower Gravel of Swanscombe, but the difference of eight fee in three miles is considerable and this spread is far more likely to belon

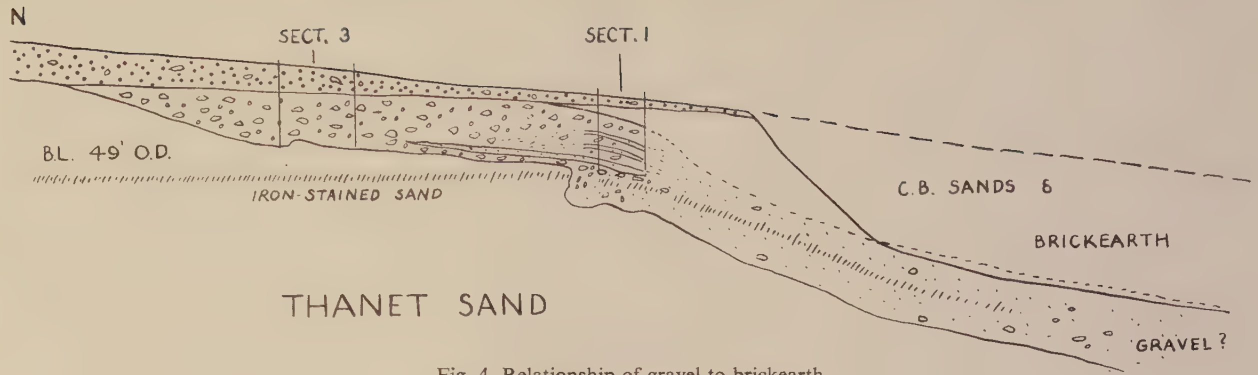


Fig. 4. Relationship of gravel to brickearth

to the same series at Stoke Newington, where there are fine sands and gravels at fifty to eighty feet O.D. This would place the terrace in the middle stages of the Clacton–Boyn Hill aggradation. The gravels to the north-east on Orsett Heath, and elsewhere, which yield Acheulian hand-axes, have a surface level of just below 100 feet.

3. THE FLINT INDUSTRY

The interpretation of the flint industry has been made by a study of the 294 artifacts obtained *in situ* from the gravel, all found within an area of a few square yards. Taking the 158 flakes from Section 3 as a representative assemblage, it has already been shown that just over half of them are in a fairly sharp or even mint condition. They cannot either have rolled far from their original position of manufacture or use, or have been derived from an earlier deposit. Not one single flake could be matched by an Acheulian bone or wood struck hand-axe finishing flake (i.e. a flake with a diffuse bulb, thin, virtual absence of striking platform and facets on the reverse in various directions resembling the surface of an Acheulian hand-axe) and no implement was found remotely resembling any product of the Acheulian Flint Industry. The material would appear to be of one industry, with no derived or mixed artifacts of any other.

The industry was mainly concerned with the production of serviceable flakes. The subsequent secondary working of some of the flakes is not agreeable to tidy, typological classification, yet in the production of flakes there was considerable method; it was no haphazard knapping of flint such as an uninitiated person would display if given a hammer and a nodule of flint and told to strike off flakes. The principle of alternate flaking was employed as a means of avoiding the critical flaking angle. It is very easy to strike a blow and remove a flake from a piece of flint when the angle between the striking-platform and the adjacent edge is low, but very difficult when it approaches right angles. This is because the resistance of the flint mass between the force lines and the exterior of the flint is so great that the resistance from the mass centre of the flint is challenged, and the force attempts to penetrate into a greater mass of the flint than the energy of the blow can deal with. As each flake tends to be wedge-shaped, it is obvious that if a series of flakes is struck off from the same striking platform, one behind the other, the critical angle will soon be reached (Warren, 1951). The principle of alternate flaking is to use the facet of the first flake removed as the striking-platform for the next, and so on. Although it may be necessary to depart occasionally from this rule, its general application causes the parent nodule to assume a roughly biconical shape. When the core is too small or unwieldy it is discarded.

The writer has experimented and produced flakes and cores by this method, identical with the products from the flint industry at Little Thurrock. The parent nodule is placed on the ground and heavy, glancing blows are struck with a suitable pebble of flint or quartzite, weighing about two pounds, approximately one quarter of an inch from the front of the striking-platform. After the removal of each flake, the core is turned over and the appropriate spot selected for striking the next blow. Sometimes two or more flakes can be removed from the same platform without ruining the core. Alternatively, the blows could be administered by the 'anvil' or 'block on block' technique, but a hammerstone produces exactly the same results with greater ease.

It will be realised that the first batch of flakes struck off round the core will have (generally) a lower flaking angle than the next batch, and so on. The typical 'Clactonian flake' with its low flaking angle is such because small flakes were not desired. Flakes were rarely removed from the core when it was of a size and shape to produce a high angle. Evidently the most prized flakes were the largish ones obtained after the cortex of the nodule had been removed. Many, mainly small, flakes do occur with rather high angles, but most of these are probably waste flakes removed in an attempt to get another useful one off the core before it was discarded.

(a) Cores

The large biconical core illustrated (No. 1, Fig. 5) is a perfect example of the result of the preceding method of flaking. It is of marbled flint, almost in mint condition, and was one foot above the Thanet Sand in Section 3. As the core was removed from the gravel, one flake fell away from an incipient fracture!

The smaller core (No. 2, Fig. 5) is also of marbled flint and in a similar condition to the larger one. It was six inches above the Thanet Sand, also in Section 3.

Three others were found and two are illustrated. One was found four feet above the Thanet Sand near Section 2, is almost in mint condition and has some delicate secondary working along one edge, which implies utilisation (No. 3, Fig. 5). The other (No. 4, Fig. 5) is of a different type: cylindrical nodules of flint appear to have been common and were used extensively, although this was the only core from such a nodule. Flakes appear to have been struck along them, like slices from a Swiss roll, presumably until the critical angle was reached. The core illustrated shows flaking from two directions. It is difficult to decide whether it would not be more accurate to call this core a chopper, for it certainly could be used as one, but as an argument against it having been intelligently flaked to such a shape, there are incipient bulbs along the edge suggesting attempts to remove more flakes, at the expense of ruining a good 'chopping' edge. This artifact was found in the scree of Section 2.

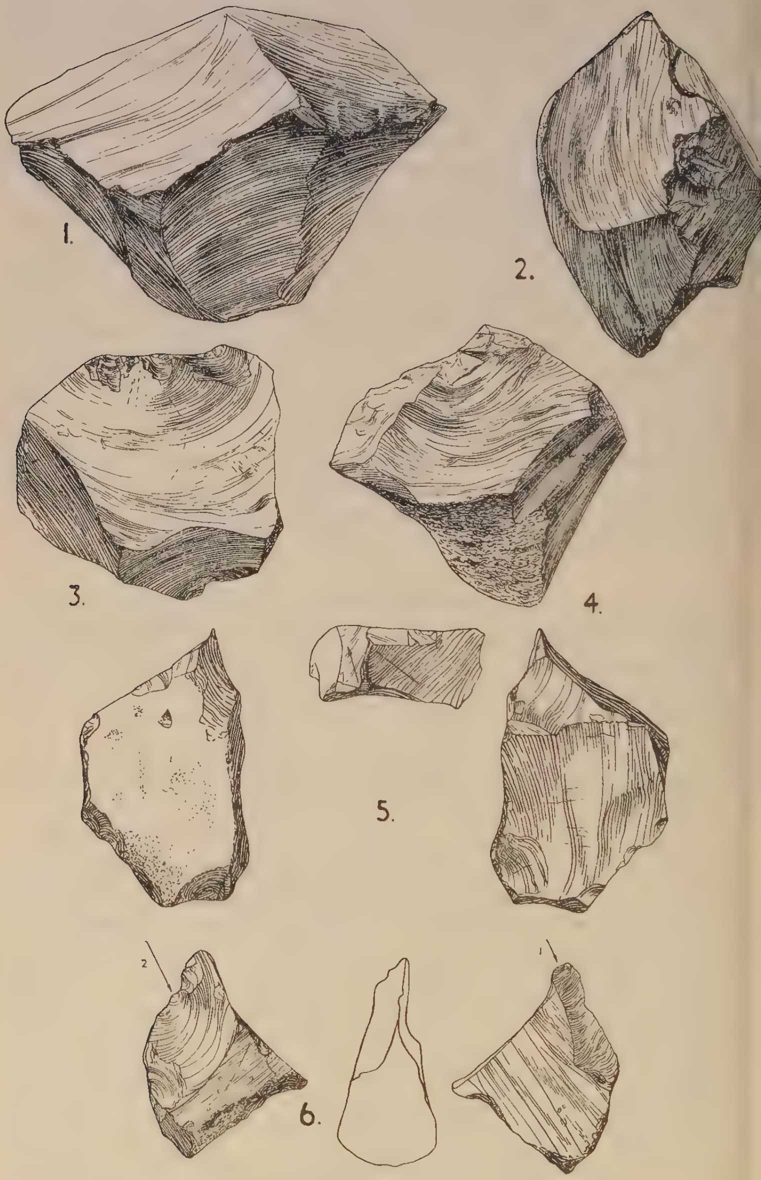


Fig. 5. Clactonian flints (reduced by $\frac{1}{2}$)

(b) Core Tools

Two artifacts of unusual type are represented by Nos. 5 and 6 (Fig. 5). No. 5 has a sharp, screwdriver-like point produced by two opposing flake scars. It is of marbled flint, slightly rolled and came from one foot above the base level of Section 1. The smaller artifact (No. 6) has some resemblance in that the pointed end is again produced by two opposing flake scars. These two implements may well have been primitive gravers, though dozens of the flakes possess similar edges which surely would have served the same purpose.

(c) The Flakes

As already stated, the main concern of the industry was the production of serviceable flakes. The probable needs of a primitive hunter and his family have been described by L. S. B. Leakey (1953) as 'weapons for hunting and killing wild animals; sharp cutting tools which can be used for skinning and cutting up the animals when killed; cutting tools which can be used to shape wood for spear shafts, etc.; tools which can be used in the preparation of skins of animals as garments; and sharp-pointed tools for digging up edible roots and for digging holes in the ground to serve as game pits'.

Many of these requirements can be satisfied with a conveniently sized freshly struck flake held in the hand as we hold a penknife, with the forefinger along the back. In the majority of cases, no secondary working would be required, as only flakes of convenient shape would be selected. Secondary working along the back edge would, however, blunt the edge and make the tool less dangerous to one's fingers. Secondary working would not improve the keenness of an edge for cutting purposes.

Nos. 7, 8 and 9 (Fig. 6) are of three flakes of this type, being serviceable as tools without secondary trimming.

> No. 7, Section 1, two feet above base level, is very rolled with edges battered all round. The two hollows on the right-hand side appear deliberately worked, but the rest of the chippings are the result of rolling. The reverse has the facets of two flakes struck from the same direction as the bulbar side, forming a straight, median ridge. The left-hand edge, when freshly struck, must have been straight and razor-like.
>
> No. 8, Section 3, one foot above Thanet Sand. Sharp condition. A fortuitous point. Bulb in left-hand bottom corner.
>
> No. 9, scree near Section 3. Rolled and edges battered. Half of bulbar face bears dendritic patination. Chipping along left-hand edge probably of natural origin.

A beak-shaped flake is extremely convenient for use, as the forefinger can rest comfortably upon the upper edge and impart a greater degree of control to whatever operation is being performed. Five such flakes (Nos. 10 to 14, Fig. 6) are figured. Their beak-like shape is fortuitous, but the secondary working on No. 10 suggests intentional blunting.

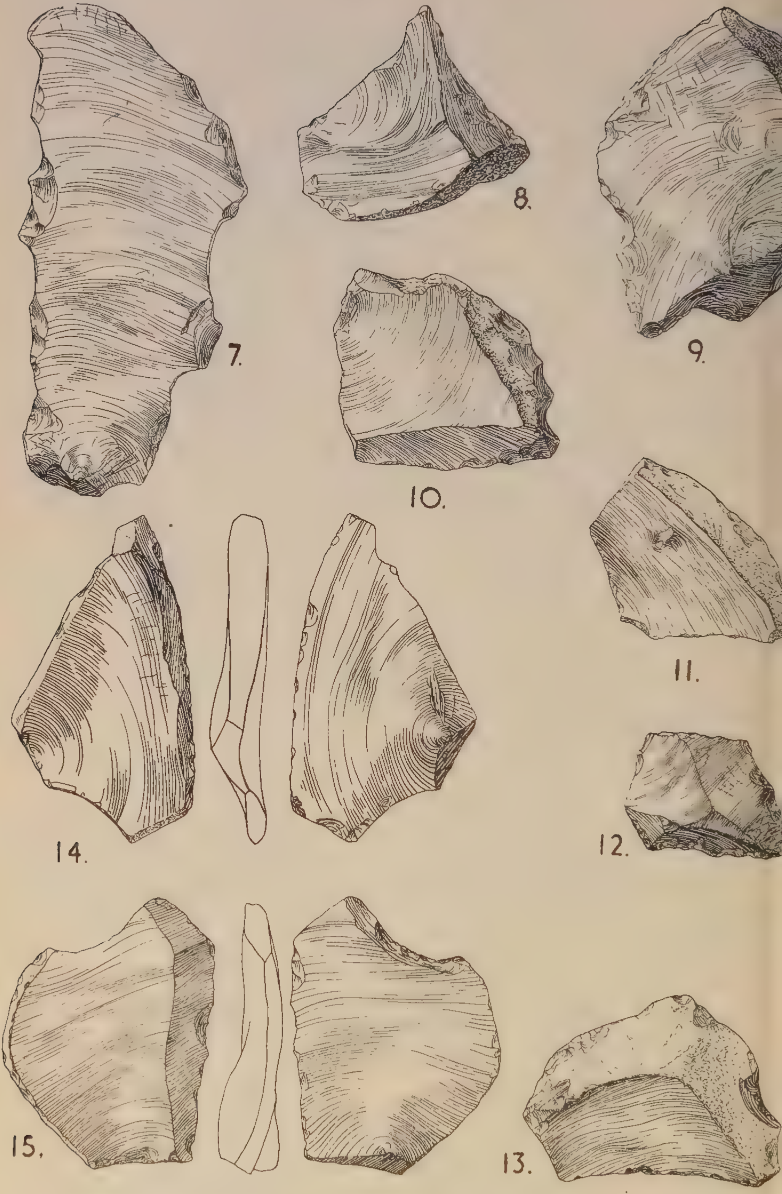


Fig. 6. Clactonian flints (reduced by ½)

No. 10, Section 2, two feet above Thanet Sand. Slightly rolled. Bulb on left-hand side.

No. 11, Section 1, three feet above base level. Slightly rolled. Bulb on left-hand top corner.

No. 12, Section 1, four feet above base level. Rolled. Bulb at top.

No. 13, Section 3, eighteen inches above Thanet Sand. Slightly rolled. Bulb on left-hand side.

No. 14, Section 2, one foot above Thanet Sand. Slightly rolled but only small chippings along the useful edge. These chippings are from both sides. Use?

Considerable numbers of the flakes have one or more hollows along the edge made by secondary working. Some are so carefully worked that they can confidently be classified as hollow scrapers. These were presumably employed for scraping thin branches and they do this job most effectively. On bone they make little or no impression. Eleven are figured as they are such a predominant feature of the industry. It will be seen that most of these flakes could have been employed for operations other than scraping branches and some, apart from those worked hollow, have secondary working of a different nature along the edges.

No. 15 (Fig. 6), Section 2, two feet above Thanet Sand. Fairly sharp condition.

No. 16 (Fig. 7), Section 2, two feet above Thanet Sand. Fairly sharp condition. Bullhead flint.

No. 17 (Fig. 7), Section 3, six inches above Thanet Sand. Fairly sharp condition. Marbled flint.

No. 18 (Fig. 7), Section 1, one foot above base level. This specimen is virtually in mint condition.

No. 19 (Fig. 7), Section 3, two feet above Thanet Sand. Rolled condition.

No. 20 (Fig. 7), Section 2, two feet above Thanet Sand. Slightly rolled.

No. 21 (Fig. 7), Section 2, two feet above Thanet Sand. Slightly rolled and thin ochrous staining.

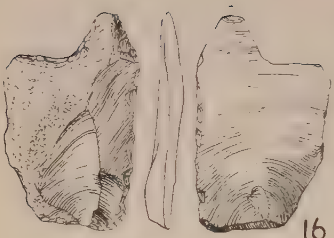
No. 22 (Fig. 8), Section 3, one foot above Thanet Sand. Slightly rolled.

No. 23 (Fig. 8), Section 3, two feet six inches above Thanet Sand. Rolled condition.

No. 24 (Fig. 8), Section 3, two feet six inches above Thanet Sand. Very rolled condition. Faint patination on non-bulbous side.

No. 25 (Fig. 8), Section 1, four feet above base level. Rolled condition. A double-hollow scraper with two worked points.

Flakes with one or more worked points occur quite frequently. Usually, secondary flakes were removed along two adjacent edges from the same side, so forming a point where the edges met. Four flake points of this type are shown (Nos. 26 to 29, Fig. 8). Another method was to trim similar adjacent edges, but from opposite sides. This would appear to be a specialised tool form and No. 30 (Fig. 9) is a fine example of this type. Three others are also figured, Nos. 31 to 33 (Fig. 9). Points have been placed vertically in these figures, so the position of the bulb on the reverse is given, if necessary.



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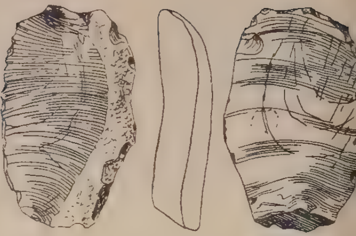

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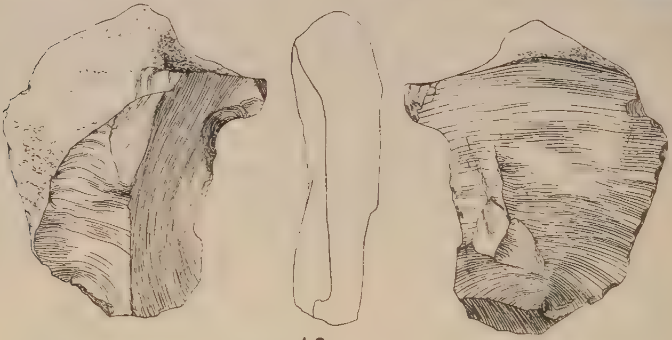

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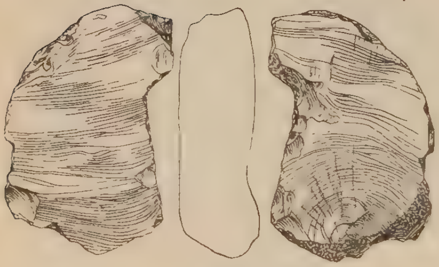

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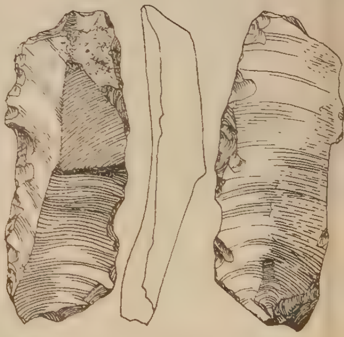

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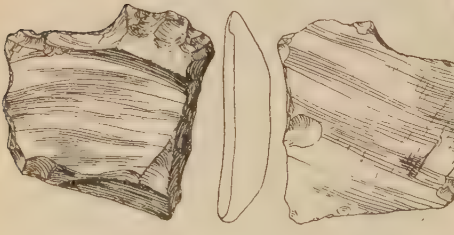

21.

Fig. 7. Clactonian flints (reduced by $\frac{1}{2}$)

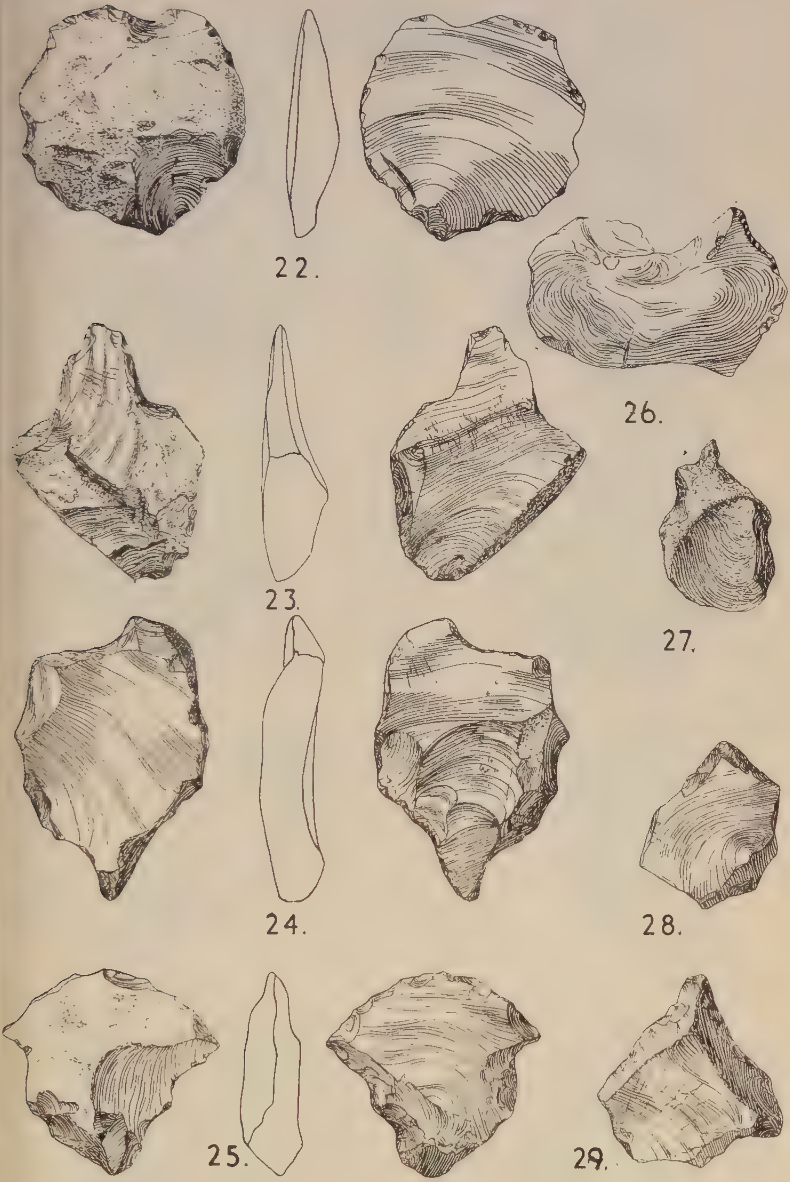

Fig. 8. Clactonian flints (reduced by $\frac{1}{2}$)

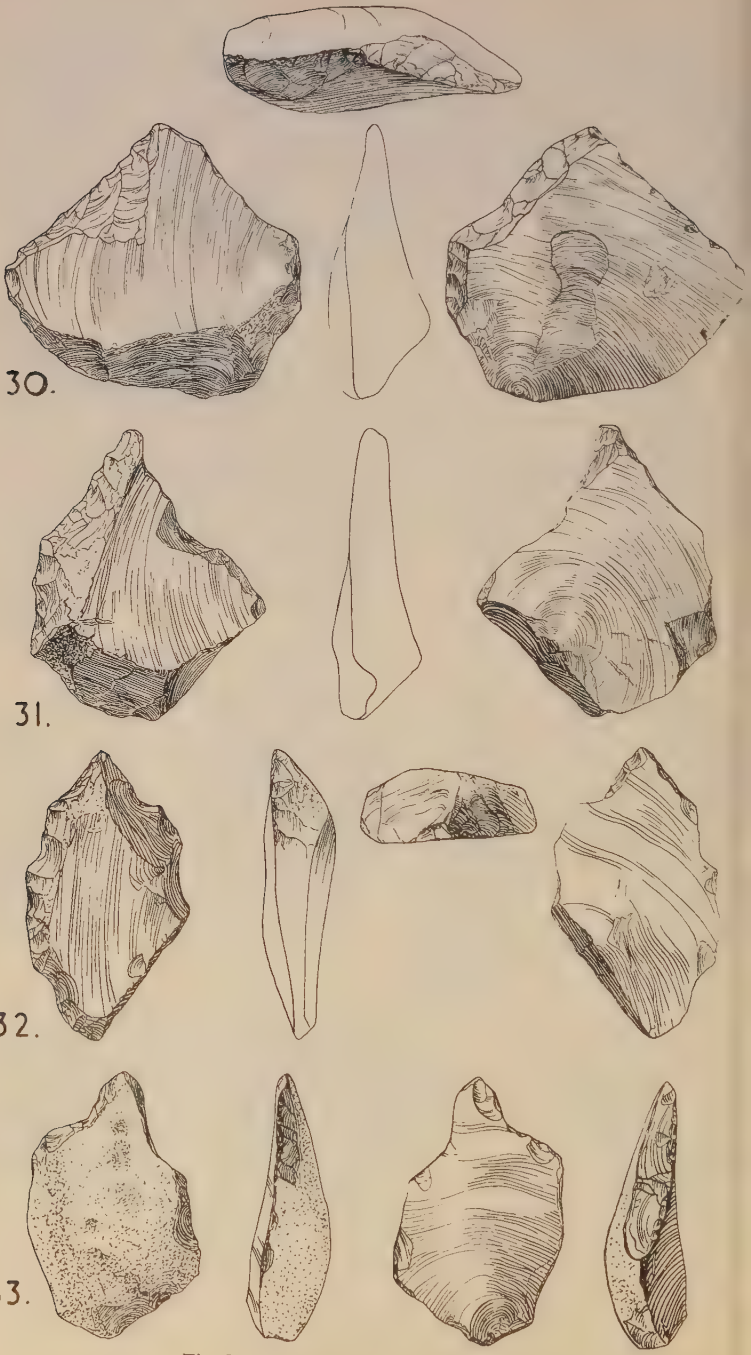

Fig. 9. Clactonian flints (reduced to $\frac{4}{7}$)

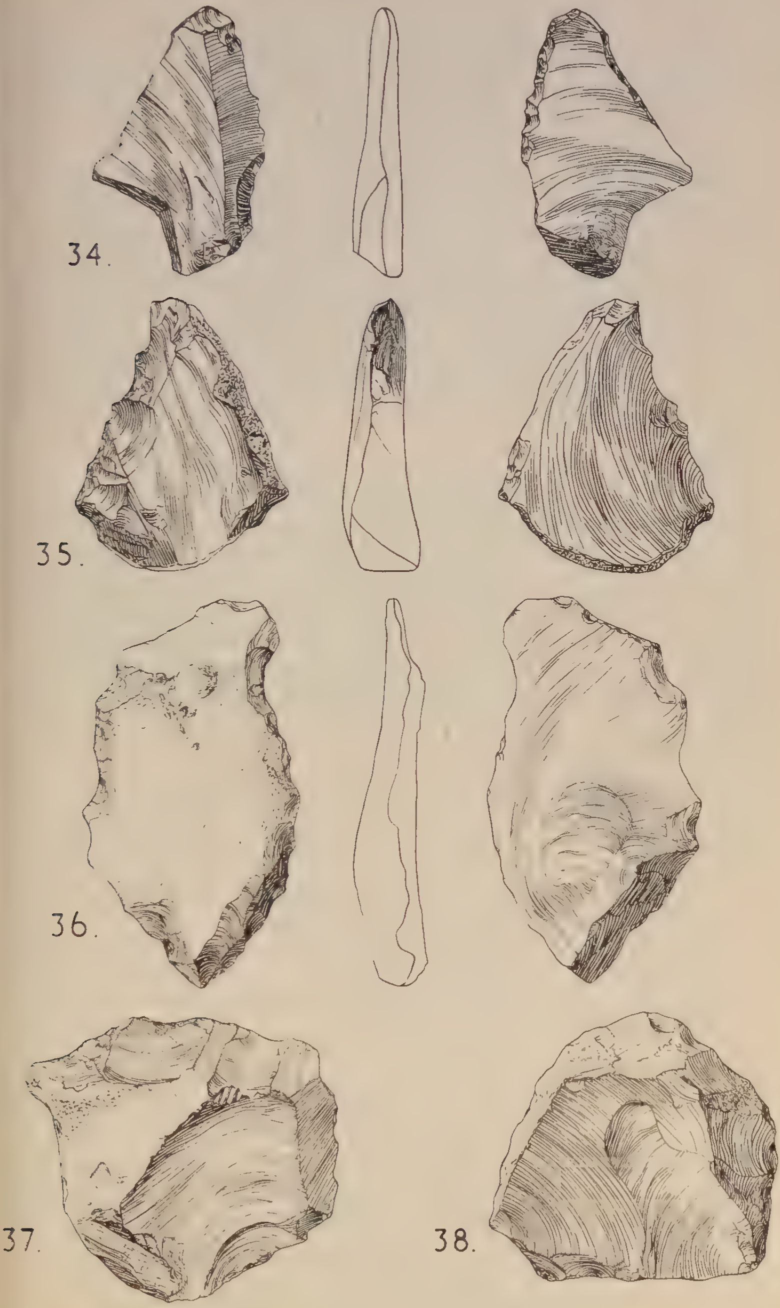

Fig. 10. Clactonian flints (reduced to $\frac{4}{7}$)

No. 26 (Fig. 8), Section 3, eighteen inches above Thanet Sand. This ha been made from a flake struck from a frost-fractured flint. Bulb on botto left-hand side. The specimen is almost in mint condition and it was onl necessary to work one edge in order to produce the point.

No. 27 (Fig. 8), Section 2, six inches above Thanet Sand. Slightly rolle condition. An unusually delicate point.

No. 28 (Fig. 8), Section 2, two feet above Thanet Sand. A rolled, patinate flake, but the secondary working is black and fairly sharp, indicating tw periods of working. The reverse is mainly cortex.

No. 29 (Fig. 8), near Section 1, four feet above base level. Rolled, patinate and ochrous stained.

No. 30 (Fig. 9), Section 2, three feet above Thanet Sand. Slightly rolle condition. Bold secondary flaking from alternate sides.

No. 31 (Fig. 9), Section 2, three feet above Thanet Sand. Slightly rolle and ochrous stained.

No. 32 (Fig. 9), near Section 1, four feet above base level. Slightly rolled

No. 33 (Fig. 9), Section 2, two feet above Thanet Sand. Slightly rolled Bullhead flint.

Other trimmed flakes are plentiful but, as already stated, are difficul to classify by form or shape. Flakes with straight worked edges do occu as do quite symmetrical convex edges, but they can hardly be classified a straight-edged scrapers or convex scrapers as every possible transitiona shape occurs and it is impossible to know where to draw the dividing line It seems likely that any form of symmetry or regularity in shape or for was fortuitous and apparent only to our eyes. The maker was probabl only concerned with the fact that secondary flaking produced a steep, blunt jagged edge which could perform different functions to the razor-lik edges of a freshly struck flake. Five examples of trimmed flakes are show (Fig. 10):

No. 34, Section 1, six inches above base level. Slightly rolled. A fairl even straight edge.

No. 35, Section 3, two feet above Thanet Sand. Slightly rolled. A straigh jagged edge.

No. 36, Section 1, eighteen inches above base level, in a thin seam of sand Mint condition. Two hollows and a curved edge.

No. 37, near Section 1, four feet six inches above base level. Slightl rolled. A boldly flaked curved edge.

No. 38, Section 2, one foot above Thanet Sand. Slightly rolled. Semi circular edge.

CONCLUSION

The gravel at Little Thurrock on the bench level of forty-nine feet O.D closely precedes the brickearth which, from its fauna, is of definite Grea Interglacial Age. It is a little more recent than the Lower Gravel at Swans combe but contains a very similar Clactonian Flint Industry.

ACKNOWLEDGMENTS

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REFERENCES

CHANDLER, R. H. 1929. On the Clactonian Industry at Swanscombe. *Proc. prehist. Soc. E. Angl.*, **6,** 79–116.

DEWEY, H., C. E. N. BROMEHEAD & H. G. DINES. 1924. The Geology of the Country around Dartford. *Mem. geol. Surv., U.K.*

HINTON, M. A. C. 1900. Grays Thurrock Area, Part I. *Essex Nat.*, **11,** 336–70.

———. 1907. Grays Thurrock Area, Part II. *Essex Nat.*, **15,** 56–88.

OSBORN, H. F. 1918. *Men of the Old Stone Age*, 28 and 157.

KING, W. B. R. & K. P. OAKLEY. 1936. The Pleistocene Succession in the Lower Parts of the Thames Valley. *Proc. prehist. Soc., London*, **2,** 56–9.

LEAKEY, L. S. B. 1953. *Adam's Ancestors*, 56–7.

WARREN, S. H. 1951. The Clacton Flint Industry. A New Interpretation. *Proc. Geol. Ass., Lond.*, **62,** 107–35.

The Structure of Sark, Channel Islands

by JOHN SUTTON and JANET WATSON

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ABSTRACT: The island of Sark is composed of a pile of metamorphic, migmatitic and granitic rocks folded about north–south axes. The structures in the three rock groups include folds, boudins, and various types of linear structures and joints. They are described and compared, and it is concluded that all are related to the same general period of deformation. The asymmetry of the folds suggests a westward movement of overlying rocks relative to those below.

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1. INTRODUCTION

THE ISLAND OF SARK, which differs from the other Channel Isles in consisting principally of metamorphic rocks, lies some twenty-five miles west of the Cherbourg Peninsula of north-western France. It is approximately eight miles east of Guernsey and twelve miles north-north-west of Jersey. Along the French coast to the east of the Channel Islands, rocks ranging from Pre-Cambrian to Devonian are exposed. The Pre-Cambrian appears in the south, more or less due east of Jersey, while Lower Palaeozoic and Devonian rocks, folded on axes running roughly east and west (see, e.g. Martin, 1953), form the northern part of the peninsula. At Cap de Flamanville they are intruded by the Flamanville Granite.

No fossils have been found in the Channel Islands themselves and, as th regional setting indicates, the rocks might well be of any age from Pre Cambrian to Upper Palaeozoic. This uncertainty gives a special interest t structural studies in the islands, and Sark, with some fourteen miles o unbroken coast exposures, provides excellent material which has no hitherto been examined in detail from this point of view. Metamorphic migmatitic and granitic rocks, each with characteristic structures, ar present on the island and our object in this paper is to describe and compar the structures of the different rock groups.

Sark is about three miles long from north to south, and at its wides point it is about a mile and a half from east to west (Fig. 1). The indente cliffs, rising to a maximum height of about 200 feet, are fairly accessibl and provide continuous three-dimensional exposures. The centre of th island consists of a level surface scored by a few deep valleys; enough roc is exposed in these valleys and in the unmetalled roads to enable the distribution of the principal groups to be determined, but structural data other than strikes and dips, can only be collected on the coast.

The first detailed account of the geology of Sark was provided by Hi whose original paper (1887) was followed by a second (1892) written i collaboration with Bonney. Hill & Bonney recognised as the lowest membe of the Sark succession a 'basement gneiss', the Creux Harbour Gneiss which appeared on the east and west coasts and was overlain by a grou of variable rocks designated on the map 'hornblende schists, etc.'. Hi originally thought that the basement gneiss was older than these rocks, bu he and Bonney subsequently showed with a wealth of field evidence tha the gneisses locally injected the hornblende schist group.

The northern tip of Sark, the almost-detached southern peninsula know as Little Sark and the west side of the neighbouring island of Brecqhou were shown to consist of granitic rocks which Hill and Bonney regarded a separate intrusions. In addition to the major groups, many varieties o later dykes were described.

In 1925 Wooldridge published a paper on the petrology of Sark and i 1926 a general geological survey by Plymen appeared. Plymen subdivide the hornblende schist group of Hill & Bonney and recognised that it wa locally overlain by mica schists. He emphasised the importance of faultin in the island and referred to the granitic rocks of the north and of Littl Sark as up-faulted blocks of Creux Harbour Gneiss.

Most of the material on which the present paper is based was collecte in 1951 and 1954 during two field trips from Imperial College, Londo

2. OUTLINE OF THE GEOLOGY

The outlines of the principal rock groups are shown on Fig. 1 and a bri general account of these groups is given below. The very numerous pos metamorphic dykes of the island have not been shown on the map, nor are they referred to in the text, except in so far as they are of structural significance. The distribution of the rock groups is determined by the effects of north–south folds, and of a large number of small faults.

(a) Rock Types

(*i*) *Hornblendic gneiss and granulite*. This group corresponds to part of the hornblende schist groups of Hill & Bonney and of Plymen, and many of its features have already been described by these authors and also by Wooldridge. It includes hornblende schists, striped hornblende granulites and banded hornblendic gneisses, with amphibolite masses and nodules of pure hornblende rock. These varieties are commonly interbanded with pink aplitic gneisses (Plymen, 1926), with highly siliceous rocks resembling felspathic quartzites (Wooldridge, 1925) and with altered semi-pelitic rocks. Many varieties, as described below (pp. 184 and 189), are migmatitic.

Hill & Bonney (1892) concluded that the hornblendic rocks were of igneous parentage; Wooldridge (1925) considered that they were probably supracrustal and Plymen (1926) referred to them as resembling basic ashes. The frequent interbanding with altered sedimentary rocks appears to favour a supracrustal origin, but there is little definite evidence. The resemblance between the hornblendic rocks of Sark and those of the Lizard was pointed out by Hill & Bonney, and also by Wooldridge.

(*ii*) *Ultrabasic bodies*. Balls and lenses of serpentinous rock often showing a zonal structure, and ranging from about a foot to twenty feet in length, occur within siliceous gneisses associated with or underlying the hornblendic schists; two small bodies occur in semi-pelitic rocks at Pot Bay. The ultrabasic rocks are limited to a few levels in the succession and are shown diagrammatically in Fig. 1. Excellent exposures near the base of the cliffs in Port du Moulin and Port à la Jument show very clearly that the serpentine balls are enclosed in banded gneisses. Those in the former locality appear to have been regarded by Hill & Bonney (1892, pp. 141–2) as forming a boss of picrite. They may also represent the steatite vein observed by MacCulloch (1811).

(*iii*) *Semi-pelitic granulites and gneisses*. A larger part of the island than has hitherto been recognised is composed of flaggy biotite granulites together with their migmatitic derivatives; these rocks appear to represent altered semi-pelitic sediments. Thin siliceous ribs and seams of hornblendic granulite are interbanded with them. The most widespread varieties are gneissose and they contain bands, augen and lenticles of pink quartzo-felspathic material. Some of these gneisses correspond to the 'banded gneisses' of Hill & Bonney (1892, pp. 125–6). The petrography of the micaceous rocks has been described by Wooldridge (1925, pp. 245–7).

(*iv*) *Granitic rocks*. Gneissose or nearly massive rocks of dioritic, tonaliti or granitic composition are apparently present at three structural levels i the island. Those of the lowest sheet correspond to the Creux Harbou Gneiss of Hill & Bonney and of Plymen (1926). A thin sheet near th middle of the succession does not seem to have been separately distinguished by these authors. An uppermost sheet, as we suggest below (p. 183 forms the granite of the north and of Little Sark.

(b) Distribution of Rock Types

Both Hill & Bonney and Plymen recognised an upward succession from Creux Harbour Gneiss, which occurs around the harbour on the east and in the region of Port à la Jument in the west, to various kinds of hornblendic rocks; Plymen showed that at several localities these were overlain by mica schists. Our own mapping suggests that the structural succession is rather more complicated than has hitherto been supposed, and ou interpretation of the arrangement of the rocks is best explained by a brie summary of what is visible in the coast sections (see Fig. 1).

An upward succession, broken by faults, can be seen by going southward from the outcrops of Creux Harbour Gneiss on either the east or the wes coast. On the west, the Gneiss, which forms the wave-cut platform between Port du Moulin and Port à la Jument, is overlain, as the earlier maps show by about 150 feet of banded hornblendic rocks. Horizons of ultrabasic balls, lying in siliceous gneisses, occur near the base of the hornblendic group which is itself overlain by semi-pelitic granulites that are brough down to sea-level by a fault in Port à la Jument.

These semi-pelitic rocks, which have a westerly or south-westerly dip form most of the coast southward to Grande Grève. They contain a conspicuous band of hornblendic rocks which can be seen high in the cliff west of Port à la Jument, near sea-level in Telegraph Bay, in two clefts t the north of the bay and in the inlet north of Grande Grève. A thin sheet o granitic gneiss underlies this band in the region west of Port à la Jument

On the east coast, the Creux Harbour Gneiss forms the base of the cliff south of the harbour and is, as previous writers have shown, overlain b banded hornblendic gneisses. Serpentine balls, enclosed in siliceous gneiss occur in the lower part of the hornblendic group. On Pointe Derrible, steepening of the westerly dip carries the Creux Harbour Gneiss and th overlying hornblendic rocks below sea-level and, according to our interpretation, these groups do not appear again to the south. They are overlai in Derrible Bay by some 350 feet of semi-pelitic migmatites. In the north west corner of the bay, a sheet of granitic gneiss, covered by about eight feet of hornblendic rocks associated with serpentine balls, comes down t sea-level from above the migmatites. It extends along the base of the Hog

Back and is covered by more semi-pelitic migmatites forming the Hog's Back itself.

In Dixcart Bay, hornblendic and granitic rocks, with semi-pelitic migmatites above and below them, appear in several blocks bounded by faults; the relations of these rocks are difficult to make out, but it seems probable that they correspond to the granitic sheet and overlying hornblendic rocks seen in Derrible Bay. They pass westward underneath semi-pelitic migmatites which continue as far as La Coupée, the isthmus connecting Little Sark with the main island.

South of La Coupée, the semi-pelitic rocks which represent the highest members of the successions seen on both the west and the east coast, pass with a south-westerly dip below the granitic rocks of Little Sark. The inclined contact can be seen in Grande Grève and followed by eye up the cliffs; it can be located on the crest of the ridge and followed south-eastward down the cliffs again into Pot Bay. There is no doubt that it is generally concordant and that the granite rests upon the metamorphic rocks.

An upward succession through hornblendic rocks into semi-pelitic rocks can again be seen as one goes northward from the outcrop of Creux Harbour Gneiss in Port du Moulin. A conspicuous hornblendic band occurs in the semi-pelitic rocks in the region of the Banquette. At the northern end of the island, the metamorphic rocks pass with a general northerly dip below granitic rocks. As in the south, the contact is generally concordant and although somewhat complicated by faulting at sea-level, it can be traced with ease up the rocky slopes to the crest of the island. It bends round the noses of several northerly-plunging folds (Fig. 1).

A generalised succession can be deduced from Fig. 1 and the evidence described above, the members appearing in the following order:

Granitic rocks	Little Sark, northern Sark
Semi-pelites	La Coupée, Banquette, Lighthouse
Hornblendic rocks	Dixcart Bay, Derrible Bay, Telegraph Bay
Granitic gneiss	Dixcart Bay, Derrible Bay
Semi-pelites	Pointe Derrible, Port à la Jument
Hornblendic rocks	Port du Moulin, Pointe Derrible
Creux Harbour Gneiss	Harbour, Port à la Jument (lowest)

This generalised succession is more complex than that given by Plymen (1926) who considered that the whole thickness of metamorphic rocks found in the island was exposed in the section at the end of the Hog's Back. It also departs from previous work in recognising the existence of considerable thicknesses of semi-pelitic rocks. The granitic rocks, according to our mapping, are sheets which keep approximately to the same structural levels throughout the island and their positions are therefore inserted in the table. The granite forming the western part of Brecqhou, which we have not visited, appears to overlie semi-pelitic rocks which in turn overlie the semi-pelites around Telegraph Bay. A glance at Fig. 1 suggests that the Brecqhou granite may be at the same level as the Little Sark and northern Sark granites.

3. ARCHITECTURE OF THE METAMORPHIC AND MIGMATITIC ROCKS

(a) Form of the Complex

Sark, as has been described, is composed of a pile of alternating metamorphic, migmatitic and granitic rocks. The intensity of migmatisation in this pile varies rapidly, and permeated and unpermeated rocks alternate within a vertical sequence of only a few hundred feet. Horizontal variations within individual groups are less conspicuous and the zones of permeation have in fact a sheet-like form resembling that of the granitic rocks.

There is no regular change in the intensity of permeation upwards or downwards, nor towards the contacts of the granitic sheets. Perhaps the least-permeated rocks are those high up in the succession towards the north-east and, as Plymen noted, those in the region of Telegraph Bay.

The onset of migmatisation in semi-pelitic rocks is marked by the appearance of small augen and *lit-par-lit* structures which increase in importance until a banded gneiss is formed. Somewhat siliceous sediments such as those seen near the foot of the steps south of Telegraph Bay develop fine felspathic streakings. More intense alteration, which can be seen at many localities above the Creux Harbour Gneiss, for example at Pointe Derrible or in Port à la Jument, causes siliceous rocks to recrystallise into pink quartz-biotite-felspar gneisses. In most varieties the new quartzo-felspathic material remains distinct from the host and homogeneous permeation gneisses are rare.

In the hornblendic group, the separation between the quartzo-felspathic material and the host-rock is also rather complete; small augen or irregular veins are sometimes developed, but more commonly the acid material forms thick bands following the foliation. Thus are developed very striking banded and agmatitic migmatites which caught the attention of earlier workers (Hill & Bonney, 1892; Plymen, 1926). Some of the most spectacular of these rocks are found on the east side of Pointe Derrible where about 150 feet of migmatites are made up of lenses and flakes of hornblendic schist set in a quartzo-felspathic matrix. Dioritic or syenitic migmatites formed by mixing of the components of the banded rocks are very rare.

The ultrabasic bodies already mentioned occur in groups along certain horizons not far above the Creux Harbour Gneiss. Each horizon is marked by a discontinuous string of lenses varying from a foot to upwards o twenty feet in length. The lenses consist almost entirely of ferromagnesian minerals and sometimes show a crude zoning. Actinolite or a dark hornblende are the commonest constituents, and these frequently make up unzoned masses. The zoned bodies contain a talc-rich serpentine core around which concentric shells of actinolite, chlorite and biotite may be developed

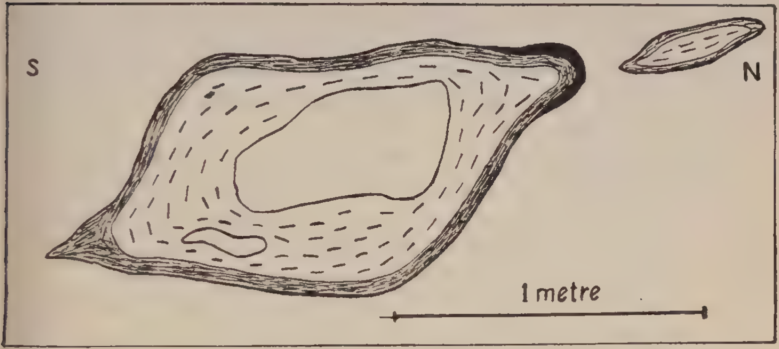

Fig. 2. Zoned ultrabasic body with a core of serpentine and talc (no ornament) surrounded by zones of actinolite (dashed) and chlorite (grey) with biotite (black) at one end. Note subsidiary talc mass. Port à la Jument

(Fig. 2). As a rule, a single lens does not possess all these zones, but comparison of several examples shows that the order of the full sequence from the centre outwards is talc—actinolite—chlorite—biotite. This is the order of zoning reported from a number of comparable occurrences. It was first described in the British Isles by Read (1934) in Unst, Shetland, and we have noted the same order in zoned balls occurring in Lewisian complexes at Loch Torridon and in South Harris. Rocks which are comparable, but which show less well-developed zoning, occur in the Lizard. Read (1934) has shown that in Unst the development of the monomineralic zones around the ultrabasic cores is the result of metamorphic differentiation. In Sark, as in the other four instances mentioned above, the characteristic feature of the setting in which zoned balls occur appears to be the juxtaposition of rocks of very different compositions during a period of prolonged metamorphism. Here, the ultrabasic balls are in contact with very acid siliceous or felspathic gneisses which are almost devoid of ferromagnesian minerals. The similarity between the Unst zoned balls and those on Sark was first noted by Dr. Mourant soon after the appearance of Professor Read's paper.

(b) Structure of the Complex

This section is concerned with a description of the folds and related structures to be seen in Sark. These structures are exhibited by both the metamorphic and the migmatitic rocks but, as we shall see, their style is largely controlled by the degree of permeation of the rocks. It is convenient to begin with a description of the larger folds, taking them in order from west to east (Fig. 1).

On the west coast, the eastern and southern parts of an elongated dome are preserved in the region between Port du Moulin and Port à la Jument. This structure brings the lower hornblendic horizon up to the surface of the island east of Port à la Jument, the overlying semi-pelitic rocks dipping off it to east and west. No easterly dips have been recorded in the inland region south and east of Telegraph Bay, and it seems probable that the anticline dies out southwards.

Another anticlinal axis traverses the ground south of the Eperquerie and is separated from the fold described above by a shallow syncline. It has a marked northerly plunge and its nose is well exposed on the east–west stretch of coast south of the Eperquerie. The base of the granite of northern Sark just touches the coast on the eastern limb of this anticline.

To the east of the Eperquerie anticline is a belt of tightly folded rocks which, as exposed on the coast, is nearly a quarter of a mile wide. Ten or so folds can be seen within this belt between the Banquette and the small granite outcrop on the east of the Eperquerie anticline. These folds, which are all less than two hundred feet in amplitude, are overturned towards the west. The axial planes dip east at angles of less than 45°: the westerly-facing limbs are short and are either vertical or overturned relative to the longer eastward-facing limbs. The low cliffs north of the Banquette are made up of a recumbent syncline whose upper and lower limbs can clearly be seen in numerous small inlets (Fig. 3).

The strong folding at the Banquette continues southward along the axial direction at least as far as Grève de la Ville; we have not been able to identify similar folding in the badly exposed ground farther south. East of the belt of complication, the rocks around the lighthouse dip north-eastward in what appears to be normal succession. It seems very probable that the small granitic islands east of the lighthouse overlie these rocks and represent parts of the upper granitic sheet.

In the south-east portion of the island, the rocks, though much broken up by faulting, appear to show a number of step-like folds whose short steeply dipping middle limbs face to the west. There is a marked monocline about a north–south axis on the east side of Pointe Derrible and two other steps can be seen between the Hog's Back and the west of Dixcart Bay. The effect of these folds, which bring down higher beds towards the west, appears to be partly counteracted by numerous faults which repeat parts of the succession. It may be noted that the step-like folds of the south-eastern region are approximately in line with the overturned folds of the north-east coast.

(c) Drag Folds

The less intensely migmatised parts of the Sark complex frequently show small-scale folds whose development is obviously closely related to that of the larger folds already mentioned. Most of these small folds have a regular asymmetrical form and we regard them as drag folds produced by relative movements or slip along the foliation planes. Some, in the region of tight folding in the north-east of the island, have a symmetrical concertina form from which no direction of movement can be inferred.

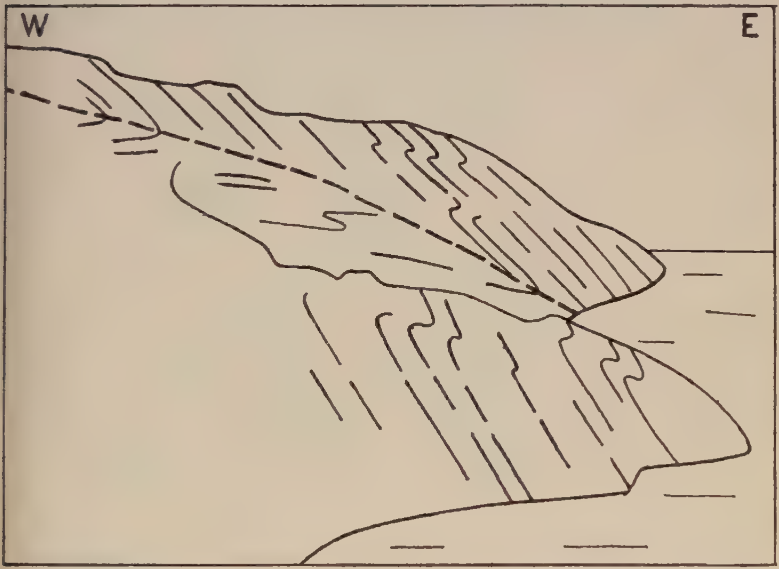

Fig. 3. Overturned syncline showing drag folds on both limbs in the background and on one limb in the foreground. The cliff is about thirty feet high. Banquette

The axes of the drag folds have a general north and south orientation. Their shorter limbs face west and their axial planes usually dip at low angles to the east. In the region of the Banquette, as we have seen, larger-scale overturned folds exist, and on the reversed limbs of these folds, the short limbs of the drag folds face eastward, down the dip (Figs. 3 and 4).

(d) Structures in the Migmatites

Perhaps the most interesting tectonic feature of the migmatitic rocks of Sark is the frequent occurrence of structures running approximately north and south whose presence suggests that movement about north–south axes

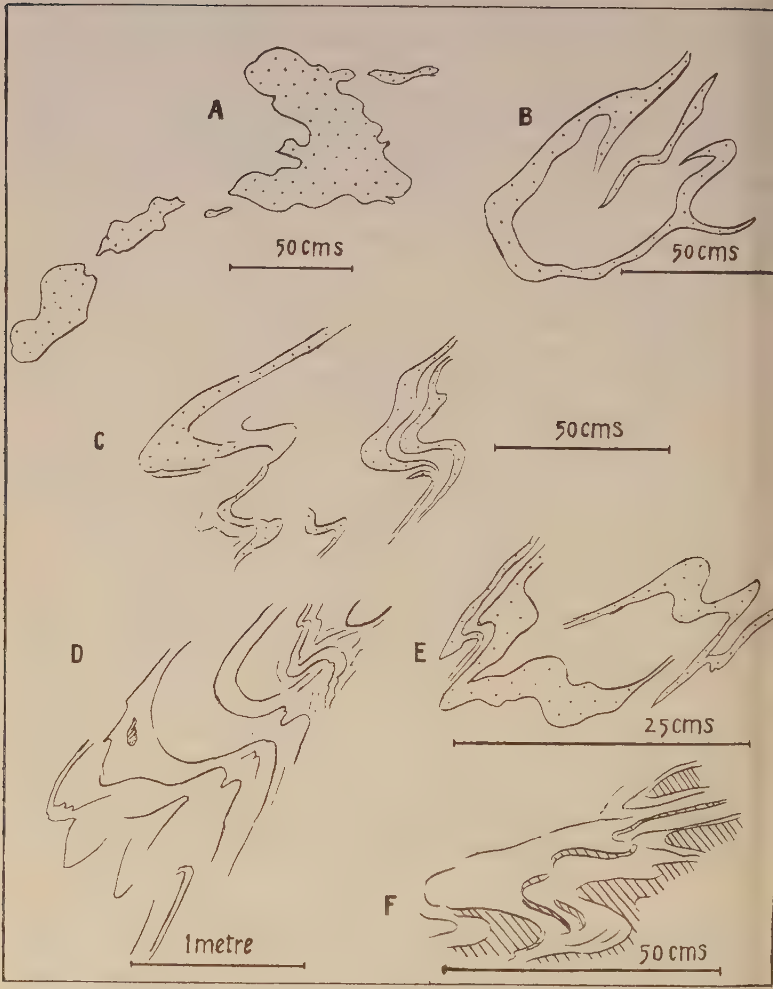

Fig. 4. Contortions in migmatitic rocks. A. Irregularly contorted felspathic masses in siliceous to semi-pelitic migmatite. Derrible Bay. B. Contorted vein material in hornblendic migmatite. North of Pointe Derrible. C. Contortions in banded hornblendic migmatite. North of Pointe Derrible. D. Contorted semi-pelitic migmatite showing drag folds on inverted limb of a fold. Banquette. E. Contorted *lit-par-lit* veins in hornblendic migmatites. North of Pointe Derrible. F. Contortions in banded hornblendic migmatite. North of Pointe Derrible

was taking place during the migmatisation. A number of different types of north–south structures in the migmatites are described below.

(*i*) *Orientated ultrabasic masses*. Many of the ultrabasic masses described in an earlier section are both flattened and elongated. The casts of ultrabasic lenses exposed south of Port du Moulin on a wave-cut platform of the underlying acid gneisses are roughly three times as long from north to south as they are from east to west. Just to the west of the foot of the public path leading to Port à la Jument, the platform of Creux Harbour Gneiss again retains the impressions left by a number of ultrabasic bodies whose long axes run 355° or 360°; one zoned mass which has escaped erosion measures about five feet from north to south and about two foot six from east to west (Fig. 2). Near the tip of Pointe Derrible, ultrabasic masses are exposed on vertical joint surfaces running both north–south and east–west. Those exposed on north–south faces are between four and seven times as long as they are high; those on east–west faces are between one and two times as broad as they are high. In the same locality, it can be seen that some of the ultrabasic bodies have been rotated; their two longest axes lie in a plane which is tipped over at an angle of about 70° to the plane of the banding of adjacent rocks, and the direction of rotation is consistent with a westward movement of the overlying rocks.

(*ii*) *Boudins of basic rocks*. In the banded hornblendic granulites and especially in their migmatitic derivatives, the more basic bands commonly show boudinage structures. In Port à la Jument lines of hornblendic boudins are separated by masses of acid pegmatitic material; this structure recalls the classic boudins described by Wegmann (1932) and indicates that the drawing-apart of the hornblendic lenses took place at a time when pegmatitic fluids could be developed.

Boudinage structures can be seen at most of the localities where hornblendic rocks are interbanded with more acid or with semi-pelitic types. The more competent basic bands are separated into strings of lenses which, in extreme cases, may be drawn apart and isolated in the more yielding gneisses surrounding them. The longest axes of the boudins run in general north and south, parallel to the other minor structures in each locality. In Port à la Jument a rotation of boudins comparable to that of the ultrabasic balls described above and in the same direction, can be seen.

(*iii*) *Quartzose segregations*. In Derrible Bay, a number of basic and ultrabasic rocks contain small masses of quartzose material which may be interpreted as segregations from the acid parts of the complex, accumulating in the shelter of more rigid basic rocks. These masses are often of irregular shapes, but they show a marked tendency towards elongation in a north–south direction. Examples seen in the cliffs on the east side of the bay have a rod-like form, with involved cross-sections and axes plunging 002° at an angle of about 2°.

(iv) *Quartzo-felspathic veins and augen.* The material introduced into the metamorphic rocks during their migmatisation has itself been subjected to deformation and the forms taken up by the streaks, bands and augen of quartzo-felspathic material enable the sense of the movements to be determined and throw some light on the way in which a permeated series of rocks reacts to deformation. The material of the bands and veins is generally a fine-grained pinkish rock composed almost entirely of quartz and felspar. Pegmatites and quartz veins are surprisingly uncommon.

Short lenses and augen are best developed in semi-pelitic migmatites, where they lie with their largest surfaces in the plane of foliation and their longest axes running approximately north and south. As seen on north–south joint faces, they have rather smooth outlines, but their shape as seen on east–west faces is generally more intricate.

Vein-like bodies of quartzo-felspathic material may either lie parallel to the banding or run discordantly through the rocks. In the more massive basic rocks, as for example in Dixcart Bay, ramifying networks of discordant veins are developed. Both the concordant and the discordant veins are commonly contorted and of irregular widths, and their shape in cross-section is very variable; they are not, however, completely unsystematic, for the axes of the contortions are remarkably constant and run parallel to the neighbouring small structures.

Typical examples of contorted and irregular veins are shown in Fig. 4. In some localities the host rock is itself so contorted that its foliation planes can hardly be made out. In others, veins follow irregular courses through a host which is more or less unfolded. It can be seen from the figure that in many instances the host rock appears to have been capable of plastic flow during the deformation. The profiles of neighbouring folds are often very dissimilar, bands and veins show extreme thickenings and thinnings, and individual folds change shape rapidly along their length. Such irregularities characterise the ptygmatic folds of Sederholm, which typically occur in deformed migmatites.

Despite the apparent irregularities, which can be attributed to the plastic condition of the migmatites at the time of their deformation, a surprising degree of regularity can be perceived in the orientation of the folds exhibited by the introduced material. As we have already mentioned, their axes have a general north–south direction. Moreover, the folds frequently tend to show the same kind of asymmetry in cross-section; they have a short limb facing west and a long limb facing east, and their form is consistent with a relative westerly movement of the rocks above them.

Some of the larger ptygmatic veins are very remarkable bodies. In Derrible Bay, a series of very large quartzo-felspathic ptygmatic veins can be seen in the cliffs. They are several feet across in their widest parts, and one example can be seen to run for a distance of at least 200 feet. Some parts of the veins are reasonably straight, but others exhibit the characteristic form of ptygmatic veins. They show extremely rapid folding, with rounded shapes and marked variations in width. One of the most interesting features about them is the fact that the shape of the folds consistently indicates westerly movement, and it is therefore reasonable to presume that they took up their form at the time of the regional deformation. On the other hand, it is quite clear that we are not dealing with the folding of originally straight veins, for their variations in thickness accord with their changes in direction and both appear to be original features. The host rocks, which consist of semi-pelitic migmatites, do not share the contortions of the veins, and it seems likely that the latter developed while the migmatites were being plastically deformed.

(*v*) *Lineation*. Crude linear structures are produced by many of the features described above. In addition, semi-pelitic rocks often show a fine striation, like the lineation of the Moine Series of Scotland. The parallel orientation of hornblende crystals produces a lineation in many hornblendic rocks. A lineation due to the elongation of quartz grains or of mineral aggregates is seen in some siliceous and semi-pelitic rocks and becomes more apparent in the vicinity of zones of permeation.

(e) The Orientation of the Minor Structures

As already noted, many of the linear structures and the axes of small folds tend to lie roughly north and south. Their trend and their directions of plunge vary from place to place in a manner which is brought out by the structural map (Fig. 5). In most localities the minor structures run slightly west of north, but in the north-west of the island they run east of north. The plunges over most of the island are towards the north, but around Telegraph Bay, in the west of Dixcart Bay and near the lighthouse, southerly plunges predominate.

The axes about which the rocks in different parts of the island are folded have been determined by plotting the poles of the foliation planes in each region on a Schmidt net. Each group of readings falls in a girdle whose axis represents the local axis of rotation of the bedding planes. These axes are shown in Fig. 5 by broken lines with an arrow indicating the direction of plunge. It can be seen from Fig. 5 that the variations in direction of the major axes are closely parallel to those of the minor structures.

A further link between the major and minor structures is provided by evidence concerning the sense of the movements effecting the folding. The axial planes of the large overturned folds in the region of the Banquette, and of the step-like folds of Derrible and Dixcart Bays, dip to the east, and the folds appear to have been formed by relative movement of upper beds towards the west. The same direction of transport is indicated by the asymmetry of many of the minor folds and even by the somewhat irregular contortions of the migmatitic rocks. Hence, there seems to be a close connection between the small-scale and large-scale structures and we conclude that they were all formed during the same general period of deformation, at the time of the metamorphism and migmatisation.

The distribution of certain types of structure reveals differences between the style of deformation of the more and the less permeated parts of the complex. These differences are well exemplified in the lower parts of the succession. South of Creux Harbour, highly permeated rocks that overlie the Creux Harbour Gneiss are thrown into many irregular folds up to about five inches across. They are succeeded upwards by slightly permeated hornblendic rocks; in these, the lineation is so intense that the banding and foliation are almost destroyed. The intensity of the lineation decreases towards the top of the cliffs where the rocks are more or less unpermeated schists and granulites showing a well-defined banding with little or no contortion.

A comparable sequence is exposed on Pointe Derrible, where agmatitic hornblendic gneisses, followed by about forty feet of semi-pelitic migmatites, overlie the Creux Harbour Gneiss. These migmatites reacted plastically, and the more acid gneisses show irregular folds flowing around the more rigid basic and ultrabasic bands. The lineation in all these rocks is weak. The agmatitic gneisses and migmatites are overlain by much less highly permeated hornblendic granulites whose lineation is very intense.

Similar occurrences of strongly lineated rocks at the margins of zones of permeation can be observed in several other localities. It seems probable that particularly strong movements took place along the junctions of the plastic migmatites and the more rigid metamorphic rocks.

4. THE GRANITIC ROCKS

As we have already noted, the granitic rocks form three more or less concordant sheets—the Creux Harbour Gneiss at the bottom of the succession, a thin central sheet and an upper sheet overlying the metamorphic succession and forming the northern and southern ends of the island. The top of this upper sheet has everywhere been eroded away, but the portion that remains in Little Sark must be at least 500 feet thick.

Although the visible contacts are generally concordant and all three sheets map out as bands running more or less parallel to the metamorphic horizons, local discordancies show that the granitic rocks could intrude the country rocks. In the cliffs north of Pointe Derrible, the contact of the Creux Harbour Gneiss cuts across banded migmatites and similar discordancies were noted by Hill & Bonney (1892) on the west coast. A granite, which probably represents the middle sheet, has locally (as in the west of Dixcart Bay) a dyke-like habit, and farther north the same sheet appears to come down to successively lower structural levels as it is followed inland from Derrible Bay to the region of Creux Harbour (Fig. 1).

The rocks of all three sheets are, as previous authors have shown, predominantly dioritic or tonalitic, hornblende being common and quartz rather scarce. The two lower sheets generally show a foliation produced by the orientation of micas, and the rocks are often distinctly gneissose. A linear arrangement of hornblende and of small ovoid felspars is often visible. The upper sheet is usually more massive-looking, but it also commonly shows a parallel orientation of hornblendes.

A crude large-scale banding produced by variations in composition or in the number of inclusions is sometimes discernible. In Pot Bay, the lowest 150 feet of the upper granite sheet consists of a coarse biotite-rich variety which passes upward into the more widespread hornblendic variety. In Grande Grève, the biotite-rich granite is noticeably thinner. A layer rich in hornblendic inclusions occurs in the south-west part of Little Sark and a zone containing large flakes of semi-pelitic migmatites crosses the islets at the northern tip of Sark. The boundaries of all these zones are parallel to the contacts and thus to the banding of the metamorphic rocks.

Inclusions of hornblendic or semi-pelitic rocks resembling the types seen in the metamorphic complex are common. The former types are particularly abundant in the upper sheet and the latter in the two lower sheets. Many of these inclusions are flaky or lenticular and lie parallel to the foliation; in Little Sark, sheet-like hornblendic inclusions may be up to six inches thick and twenty yards long, and several inclusions may occur in line along a single foliation plane. At Venus Pool, east of Port Gorey, a large flake of hornblendic granulite is bent into an upfold (Fig. 6). The petrological changes in these hornblendic inclusions have been described by Wooldridge (1925).

The uppermost granitic sheet, both in the north and in Little Sark, contains numerous ovoid pods, generally not more than a foot in length, composed of coarse unoriented hornblende crystals with a little felspar. These pods lie with their long axes parallel to the linear orientation of the hornblendes in the surrounding rock.

Inclusion of ultrabasic rocks other than hornblende rocks of the type described above are rare, but two balls of serpentine, surrounded by narrow rims of actinolite, chlorite and biotite, can be seen enclosed in the Creux Harbour Gneiss at a point below high tide mark, immediately north of Port du Moulin.

The foliation of the granitic rocks is parallel to that of the metamorphic rocks, and the foliation in the upper sheet can be seen to follow the gentle folds shown by the country rocks at the north end of the island. Where the contacts are discordant, the foliation may locally pass across them into the country rock. The linear elements of the granitic sheets—the axes of elongation of xenoliths and the orientation of hornblendes and felspars— are likewise parallel to those of the adjacent country rocks. Over most o the island they plunge northward, but in the eastern part of Little Sar the plunge is to the south. The strike of the surfaces of platy xenoliths i the granitic sheet of Little Sark is shown in Fig. 5. The poles of thes surfaces, when plotted on a stereographic net, fall on a great circle whos axis plunges gently NNW. This arrangement suggests that the attitude o the xenoliths is controlled by folding about a NNW. axis.

The structural pattern within the granitic sheets as revealed by the linea and planar structures conforms to that of the metamorphic and migmatiti rocks (Fig. 5). It seems improbable that this pattern is a mimetic one inherited passively from a migmatitic parent. The granitic sheets are mad

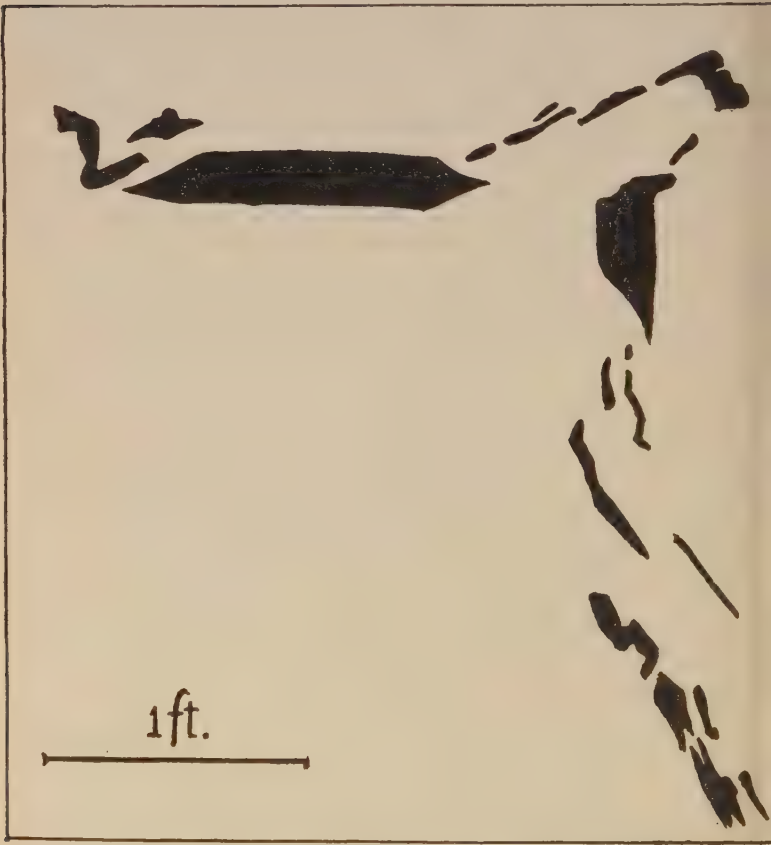

Fig. 6. Contorted line of hornblendic inclusions in Little Sark granite, Venus Poo

up of fairly uniform rocks in which the oriented hornblendes are more or less evenly distributed. The metamorphic rocks as we have seen are almost invariably banded, and it seems certain that a complete reconstitution, involving the destruction of the earlier fabric, must have taken place if the granites were formed *in situ*. Moreover, as we shall see, the joint pattern of the granitic rocks, which can hardly be an inherited feature, is closely related to the linear and planar structures. We therefore conclude that the rocks of the granitic sheets were subjected to the same deforming forces as the metamorphic complex during or after their emplacement.

There is little that can profitably be said of the origin of the granitic sheets. They might, in view of their conformable structure and richness in inclusions, represent horizons of very completely granitised country rocks. It appears to us more probable that they consist largely of intrusive material which, by making its way along a number of adjacent bedding planes, split off flakes and zones of the country rocks which were incorporated in the granitic sheets.

5. THE FRACTURE SYSTEMS

Four categories of fractures can be recognised in Sark: (a) Barren joints, (b) Joints filled by dykes, (c) Faults, (d) Low-angle thrusts.

(a) and (b) Joints

The orientations of barren joints and of joints containing dykes have been measured both in the metamorphic complex of the main part of the island and in the granitic rocks of Little Sark. There seem to be no significant differences between joints with and without dykes, and the two categories are therefore considered together. The relevant data are summarised in Fig. 7A and B (joints) and Fig. 8 (dykes). The poles of joint planes in the metamorphic rocks are shown in Fig. 7A and those of joint planes in the Little Sark granite in Fig. 7B.

Although the diagrams present a rather blurred picture, certain definite features emerge from them both. In the metamorphic rocks there are strong north–south maxima, corresponding to steeply dipping east–west joints. Less well-defined east–west maxima indicate the existence of steeply dipping north–south joints. In the field, the east–west joints, which show up most prominently in Fig. 7A, are usually the best developed from the point of view of the regularity and extent of individual planes, and they have the greatest effect upon the coastal topography; most of the rock knobs and buttresses in Derrible Bay, for example, are terminated by vertical east–west joints. These major joints are in most localities more or less perpendicular to the lineations and fold axes, and they may therefore be taken as **ac** or cross-joints. The less conspicuous north–south planes represent **bc** joints.

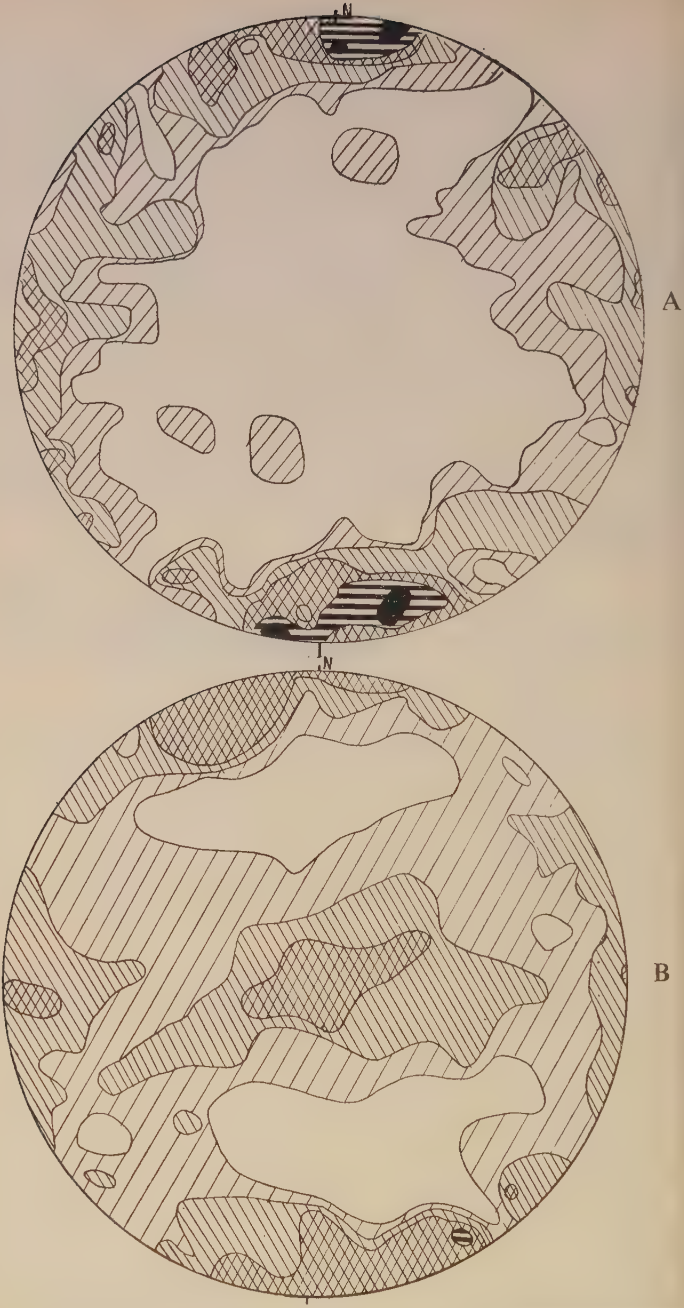

Fig. 7. Stereographic projections, on lower hemisphere, of poles to joint plane
Contoured at $\frac{1}{2}$, 1, 2, 3%. A. Joints in metamorphic rocks. Readings from whol
Island except Little Sark. B. Joints in Little Sark granite. Readings compiled by M.
Rickard and J. Shackleton

The joint diagram of the Little Sark granite (Fig. 7B) was prepared by M. J. Rickard and J. Shackleton, for whose co-operation we are very grateful. The pattern is clearly similar to that shown by the metamorphic rocks, but the east–west joints, represented by the north–south maxima, are rather less prominent, and the north–south joints include not only steeply dipping but also gently inclined planes, so that they appear on the diagram as a complete east–west girdle instead of a pair of maxima. The rarity of flat joints in the metamorphic complex is probably accounted for by the fact that the gently dipping foliation surfaces in these rocks provided ready-made parting planes.

Allowing for the differences mentioned above, the joint patterns of the metamorphic and the granitic rocks are very similar and both have a regular geometrical relationship to the structures associated with the folding. It therefore seems very probable, firstly, that the joints are related to the folding and, secondly, that the joint pattern of the granite is the product of regional stresses rather than of stresses related to the cooling of the granite itself.

The majority of post-metamorphic dykes on Sark are steep and very many of them are vertical. Their orientation is therefore well brought out by a histogram of their strike directions (Fig. 8). The figure shows a very marked concentration just north of east (060°–080°) and a small concentration at right angles to it (140°–170°). Comparison with Fig. 5 shows that these maxima are respectively perpendicular to and parallel to the common

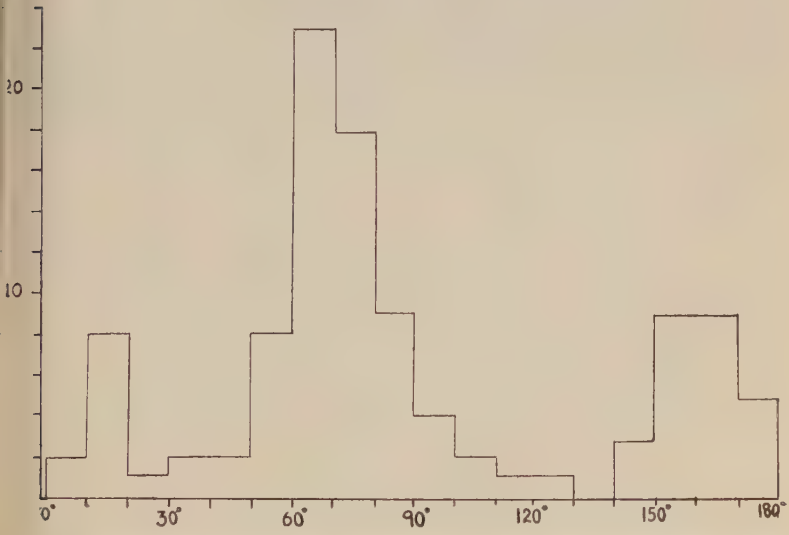

Fig. 8. Histogram of the strike directions of all types of post-metamorphic dykes

direction of lineation and axis of folding. It is thus apparent that a hig proportion of the dykes follow the **ac** and **bc** joints produced in connectio with the folding. The **ac** or cross-joints, which represent tension fracture are the most favoured.

An attempt was made to plot the strike direction of dykes within limite areas and to compare the results with the local fluctuations in the direction of the linear structures. There does not, however, appear to be a close loca correlation between the strike of the dykes and the linear structures. Th dykes show less variation, and exhibit their usual pattern in regions suc as the north of the island where the lineation direction is aberrant.

(c) Faults

Almost every gully around the coast contains a minor fault, filled with little loose rubble, a reddened gouge or a silicified breccia, but most o these faults have a very small throw. The faults are probably of man different ages; some may antedate the dyke intrusions, some are contem porary with certain of the dykes and others cut and displace all dyke Only the larger faults are shown on Fig. 1, and it will be seen that eve these only have a relatively small effect. The largest fault is probably th one on the north side of Creux Harbour which brings together rocks wit a markedly different strike and dip.

About 50% of the fifty or so faults whose direction has been measure strike either ENE. or NNW., but the remaining examples run in ever possible direction and it cannot be claimed that they have a well-marke pattern. Similarly, the sense of movement on the faults does not appear t be consistent and adjacent faults sometimes have the opposite effects; i Telegraph Bay and Port du Moulin (Fig. 1), pairs of opposed faults le down wedges shaped like a slice of cake. One receives the impression tha many of the small faults may be due to uneven settling of the comple rather than to regional forces.

Although the principal movements appear to have been vertical, evidenc of horizontal shifts is not uncommon. On the headland north of Telegrap Bay vertical dykes are shifted laterally by a number of small faults; nort of Pointe Derrible, an earlier fault is similarly displaced by a later on Here again the directions of movement are not consistent.

More interesting evidence of horizontal movement is provided by som of the dyke intrusions which seem to fill spaces opened by relative later movement of two adjacent blocks: 120 yards north of the Eperquerie, a irregular dolerite fills the spaces between blocks of granite bounded b steep joint-planes (Fig. 9B). Each block apparently moved eastwar relative to that to the south of it. The dyke structure here is similar to som of the structures figured by Kaitaro (1952).

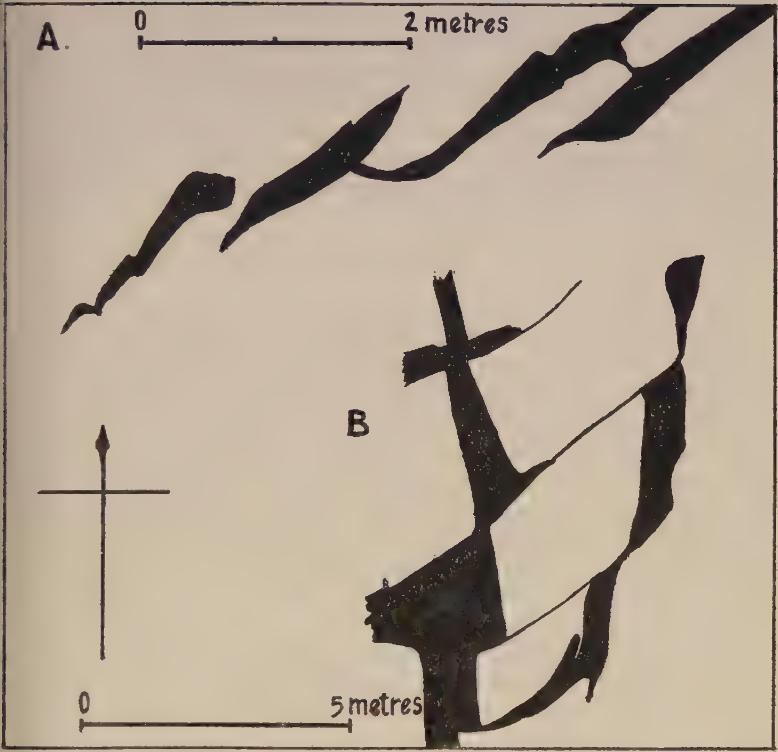

Fig. 9. Dolerite intrusions filling complex fracture systems. A. *En echelon* dykes. Eperquerie. B. Dykes intruding spaces between joint blocks. 120 yards north of Eperquerie. Dolerite shown in black in both figures

At a number of localities, including the Eperquerie, the wave-cut platform of Telegraph Bay and the cutting south of the tunnel from the new harbour, small doleritic or lamprophyric dykes occur *en echelon*. These *en echelon* dykes can be regarded as filling shear or tension fractures opened by lateral movements of the blocks on either side of them; they thus represent incipient fault zones (Fig. 9A). In all, six groups of *en echelon* dykes indicating horizontal movements were found; all strike practically east and west and all except that at the Eperquerie suggest relative eastward movement of the more northerly block. Within the island, there is no means of estimating the age or significance of this movement.

(d) Low-angle Thrusts

On the west coast in the regions north of Telegraph Bay, a number of gently dipping planes of brecciation are exposed in the cliffs. They can occasionally be seen to behead a dyke or a pre-existing fault, and therefor some at least of them must be of late formation.

The direction and amount of movement along these late thrusts ca seldom be determined, but in the cleft at the south-west side of Port d Moulin, the upper part of a branching dolerite dyke is shifted a few fee towards the east. In Port à la Jument, on the other hand, a rough fractur cleavage between two thrusts indicates westerly movement of the overlyin block.

CONCLUSIONS

The tectonic history recorded in the rocks of Sark appears to have begu with a phase of folding and intense deformation accompanied by metamorphism and migmatisation; the precise effects of this deformatio varied with the physical state of the rocks, and the less permeated zone formed rather larger-scale and more regular structures than the mor plastic zones of permeation. The intrusion of granitic sheets followed th migmatisation while the stresses which caused the folding were still active After an unknown interval of time, several groups of dykes were intrude along joints whose directions are closely related to the fold structures. Th formation of small faults took place in several stages during and after th intrusion of the dykes, but the relation of these faults to the earlier structures is not apparent. The folds, linear structures and joints of the metamorphic and migmatitic rocks have an apparently simple pattern consisten with movement from east to west about north–south axes. The structura pattern of the granitic rocks very closely resembles that of the metamorphi complex and was probably produced during the same period of deformation. For this reason we suggest that the formation of both the metamorphic and the granitic rocks took place during the same general period The granitic rocks appear to be syntectonic and it would be of interest t compare their structures with those shown by the granites of the othe Channel Islands.

The area of Sark is so small that the island cannot necessarily be assume to provide an adequate sample of the tectonic pattern of the rock group exposed there. Nevertheless, some points of general interest arise from th facts presented in this paper. The north and south trend of the fold syste in Sark appears to be at variance with the trend of Hercynian structures i the Palaeozoic rocks of the Cherbourg Peninsula twenty-five miles to th east, and with the trend of structures in Brittany to the south. Despite som fluctuations, the folds in these regions run predominantly on east–wes lines (see, for example, Gignoux, 1950, fig. 11). A further contrast i provided by the fact that in Sark, as we have seen, the folding was accompanied by metamorphism leading to the production of gneissos migmatites whereas in the nearby parts of France the grade of meta morphism appears to be usually rather low. Bigot, for example (1925), found a recognisable Cambrian fauna preserved in the 'schistes pourpres' which rest unconformably on the metamorphic 'quartzo-phyllades de Saint Lo' at Carteret in the Cotentin, which is one of the places nearest to Sark on the French coast.

On the other hand, the resemblances between the rocks of Sark and those of the Lizard in Cornwall appear to be more numerous than has hitherto been realised. Hill & Bonney and Wooldridge noted many petrological links between the two regions and these are strengthened by the discovery of zoned serpentine bodies in Sark. The structural resemblances are even more striking.

The structures shown by the rocks of the Lizard, to which we were introduced a number of years ago by Professor R. M. Shackleton, have been recently described by L. D. Sanders (1955) who has made new observations on the Kennack Gneiss, with the included bodies of serpentine, and on lineations in the hornblende schists. These structures are very similar in style to those of Sark and these linear structures have, as in Sark, a general north–south trend. The predominantly flat-lying attitude of the foliation and of the main rock groups is another point of resemblance which may have some value, for, on the whole, complexes of this nature in other parts of the British Isles, such as the north-west Highlands, tend to have steeper dips and exhibit a rather different tectonic style.

The points mentioned above suggest a contrast between the rocks and structures of Sark and those of the adjacent parts of France. The question arising from this contrast is whether the structures of Sark, and possibly also of the Lizard, are so different in style and orientation from those of the adjacent parts of the Hercynian chain that they are likely to be pre-Hercynian in age. The small size of the island makes this problem difficult to resolve. The compilation of a structural map of the other Channel Islands might provide further information and might at the same time throw light on the relationship between the older gneisses and the younger granites of the islands.

REFERENCES

BIGOT, A. 1925. Sur la presence de Trilobites et d'Archaeocyathides dans les couches cambriennes des environs de Carteret (Manche). *C. R. Acad. Sci., Paris*, **180,** 1237–39.

GIGNOUX, M. 1950. *Géologie stratigraphique*. 4th Ed. Masson. 1–735.

HILL, E. 1887. The rocks of Sark, Herm and Jethou. *Quart. J. geol. Soc. Lond.*, **43,** 322–35.

———— & T. G. BONNEY. 1892. The hornblende-schists, gneisses and other crystalline rocks of Sark. *Quart. J. geol. Soc. Lond.*, **48,** 122–47.

KAITARO, S. 1953. Geologic structure of the late Pre-Cambrian intrusives in the Avo area, Aland Islands. *Bull. Comm. géol. Finl.*, **1–71,** 162.

MACCULLOCH, J. 1811. Accounts of Guernsey and the other Channel Isles. *Trans. geol. Soc. Lond., Ser. I,* I, I.

MARTIN, N. R. 1953. The structure of the granite massif of Flamanville, Manche, north-west France. *Quart. J. geol. Soc. Lond.*, **108,** 311–41.

PLYMEN, G. H. 1926. A preliminary survey of the geology of Sark. *Geol. Mag.*, **63,** 255–64.

READ, H. H. 1934. On zoned associations of antigorite, talc, actinolite, chlorite, and biotite in Unst, Shetland Islands. *Miner. Mag.*, **23,** 519–40.

SANDERS, L. D. 1955. Structural observations on the south-east Lizard. *Geol. Mag.*, **92,** 231–40.

WEGMANN, C. E. 1932. Note sur le boudinage. *Bull. Soc. géol. Fr.*, **5** *serie*, 2, 477–91.

WOOLDRIDGE, S. W. 1925. The petrology of Sark. *Geol. Mag.*, **62,** 241–52.

DISCUSSION

DR. A. E. MOURANT said that, many years previously, he had seen a paper in the PROCEEDINGS of the Association by Professor H. H. Read on metamorphic structures in Shetland. He had noticed a remarkable similarity to the rocks of Sark and recognised in particular that, as Dr. Sutton had just said, large ultrabasic nodules with concentric structure occurred in that island. Ever since then he had hoped that someone of Professor Read's school would make a study of Sark. That hope had now been very amply fulfilled and he congratulated the Authors on their achievement.

He mentioned that the adjacent island of Brecqhou showed the upper Sark granite overlying the schists, the westwardly dipping junction, being very well exposed at two points, separated by a fault on the south coast. The next nearest islands, Herm and Jethou, were entirely composed of a pale grey granite somewhat resembling that of Sark in its field appearance. On Jethou it showed slight foliation while at the northern end of Herm it was full of basic xenoliths. The Paternosters reef north of Jersey and the Minquiers to the south were mainly composed of granite gneiss, with occasional rafts of schist, one at least of those on the Minquiers showing complicated small-scale folding. A detailed comparison of all these areas with Sark would be interesting.

The speaker supported the Authors' tentative conclusion that the metamorphism of Sark was earlier than the Armorican orogeny. He said that on the adjacent Cotentin coast the undoubtedly Armorican Flamanville granite was surrounded only by a comparatively narrow rim of thermal metamorphism in the Devonian and earlier sediments. Outside the aureole Palaeozoic rocks, extending almost certainly down into the Cambrian, were unmetamorphosed. The only intensely metamorphosed sediments were found near Cap La Hague where they apparently formed part of a mainly plutonic complex which here and in Alderney underlay the unconformable base of the unmetamorphosed lowest Palaeozoics, probably of Cambrian age.

The speaker referred to the joint systems of the Jersey granites and strongly supported the Authors' proposal that workers of the geology of the Channel Islands should co-operate in preparing a structural map of the whole area.

MISS D. C. JUDGE said that she found the Authors' observations on the folds found by mapping trails of schlieren within the granites of great interest. In ground which she had recently mapped in north-west Donegal, the youngest member of a plutonic complex showed similar phenomena. Here, however, major folds which were observable outside the granite contact were mappable in the granite by the trends of schlieren and rafts. Evidence in the field based on major and minor structures pointed conclusively to the granite being later than the folds, since within the envelope the latter were cut abruptly by the granite which could be shown to be of undoubted intrusive origin.

While Miss Judge did not wish to infer that the Sark granites were metasomatic, she enquired whether those folds recognised by the Authors could in fact be of a similar nature, being remnants of folds existing prior to the emplacement of the Sark granites and not, as suggested by the Authors in their paper, of post-granitic age.

DR. J. L. KNILL said that he wished to support Dr. Sutton with reference to the joint patterns found on Sark. The speaker had recently studied joint patterns in an area of Dalradian rocks, composed of metamorphosed sediments and intrusions in the south-west Highlands of Scotland. During this investigation, individual patterns were studied in detail, and thousands of joints were measured and subsequently plotted.

The metamorphosed intrusions have, over part of the district, a strong columnar jointing and, when traced along the strike for ten miles into an area of greater deformation, develop a new joint pattern. This new pattern is composed of essentially two joint-sets in the **ac** and **bc** directions relative to the attitude of the individual sill and is very similar to those illustrated by the Authors from Sark. Diagonal joints are unusual in the metamorphosed intrusions of this more deformed area. However, the metamorphosed sediments have a joint pattern different to that of the intrusions and this pattern is composed of an **ac** joint-set with an associated pair of diagonal joint-sets.

It is clear, from this example, that joint-patterns developed in metamorphic rocks are controlled by the mode and conditions of deformation, as well as the nature of the deformed rock.

DR. A. T. J. DOLLAR congratulated the Authors on a most stimulating account of structural researches at a locality where former geological investigations have been largely petrological. Their results raised a number of interesting problems, among which were the jointing in the 'granitic' (diorite-gneiss and quartz-diorite-gneiss) rocks of Eperquerie in the north, Little Sark in the south, and the western half of the islet of Brecqhou in the west, the jointing of the basic dykes, and the fault system throughout the island.

If the essentially north–south orientation of fold-axes and lineation, coupled with the asymmetry of many of the folds, is accepted as evidence for a single period of approximately horizontal compressive stress, directed east–west, then can the Authors suggest any likely reason for the absence of either one or two conjugate sets of compressional joints (Mohr joints) in the rocks of 'granitic' composition? A stereographic projection of poles of joint-planes in the granitic rocks (Fig. 7B), shown on the screen, suggested the dominance of two sets of vertical planes, striking north–south and east–west respectively, and a third set of planes which were substantially horizontal, but gave no indication of Mohr-type joints.

Further, do the Authors ascribe the initiation of the NNE.–SSW. faulting to 'the same general period of deformation' (Circular 594), as that of the folding and lineation, or to a different period? Former workers have attributed the faults to compressional stress parallel to a NW.–SE. direction rather than to one of east–west trend. What views do the present Authors hold about the north-westerly stress direction in the light of their recent work?

Finally, how do the joint patterns in the basic dykes accord with those of their country rocks?

THE AUTHORS in reply thanked Dr. Mourant for his contribution and expressed the hope that a structural map of the Channel Islands as a whole might be constructed in the near future.

The folds shown up by schlieren in the granitic sheets might well, as Miss Judge had suggested, be of pre-granitic age. However, the granitic rocks themselves showed lineations parallel to the axes of these folds and the Authors had therefore inferred that movements about the same axial direction had continued during the formation of the granitic sheets.

In reply to Dr. Dollar, the Authors stated that they had made only a preliminary study of the joint systems and it was possible that more detailed work might reveal subsidiary maxima related to conjugate joint sets in the upper granitic sheet. This sheet was relatively thin, by comparison with its lateral extent, and the simplicity of the joint pattern might be connected with this fact.

The majority of the faults on Sark appeared to be contemporary with, or later than, the post-metamorphic dykes and it seemed probable that their formation was not connected with the deformation accompanying the metamorphism. The orientation and sense of movement of the faults were variable and the Authors felt that it would be difficult to establish with certainty the nature of the forces which produced them. The jointing of many of the post-metamorphic basic dykes appeared to be controlled by the orientation of the dyke walls rather than by the regional joint pattern.

The Hydrogeology of the Clarendon Plains, Jamaica

by S. A. G. TAYLOR and L. J. CHUBB

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ABSTRACT: The plains of Clarendon, in south Jamaica, have always suffered from irregular and inadequate rainfall, with long periods of drought, and a scheme to irrigate the area from surface sources proved a failure. Geological investigations have revealed that there are two subsurface water-bearing horizons, separated by an impermeable clay. The upper horizon, consisting of alluvial gravel, and drawing its water from the rainfall on the plains themselves, yields only limited supplies; the lower horizon, however, which is in the Tertiary limestone underlying the clay, provides an abundance of water. This is derived from rainfall on the surrounding limestone hills, which are intensely karstified, so that almost all the precipitation disappears underground and makes its way below the Clarendon Plains. This water is tapped by means of borehole wells, and distributed through irrigation canals. Thus this formerly arid area has been transformed, and its sugar production has increased more than seven-fold.

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1. INTRODUCTION

THE CLARENDON PLAINS, which are situated on the south side of Jamaica, midway along the length of the island, occupy an approximately square area of over 100 square miles. The plains are floored with alluvium, and are bounded on three sides by hills of the Tertiary White Limestone Formation, the Manchester Highlands on the west, the Mocho Mountains on the north, and the Braziletto Hills on the east. In the middle of the south side of the plain, Tertiary Limestone again rises to the surface, to form the small Kemps Hill. The plain is continued beyond this hill towards the south-east, as the triangular District of Vere, which terminates in Portland Ridge, another Tertiary Limestone mass, about five miles south of the Braziletto Hills (see map, Fig. 1).

The area is drained by two rivers, the Milk River, which enters the plain at its north-west corner, and flows south along the foot of the Manchester Highlands; and the Rio Minho, which enters at the north-east corner and also flows south, following a meandering course parallel to the Braziletto

Hills, but in Vere turns towards the south-west. Most of the area of the plain is drained by tributaries of the Milk River. The average rainfall varies from forty inches near the coast to fifty-five inches under the foot-hills. But these figures are misleading as much of the rain falls in two months of the year, and for several years in succession less than thirty inches has been recorded. Before the irrigation of the plain was successfully accomplished it was a well-established tradition that planters could hope to reap only one good crop in three.

Since 1876 schemes for irrigating the plains have been under consideration, but it was not until 1900 that a proposal was adopted whereby water would be abstracted from the Milk River, near its point of entry into the area, and carried south-eastwards across the plain by a contour canal to Raymonds, in Vere, where a storage reservoir would be built. The project, which was completed in 1906, failed disastrously. The Milk River went dry

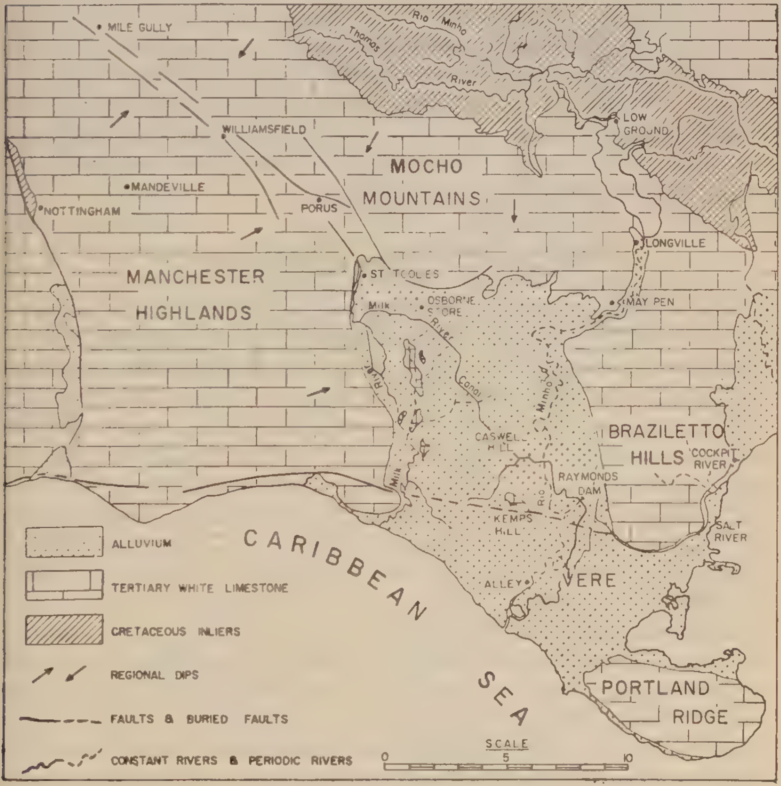

Fig. 1. Geological map of the Clarendon Plains and their catchment area

repeatedly between 1908 and 1915, and remained dry continuously from 1920 to 1931, and it was found that the Raymonds Reservoir, being constructed on thin pervious alluvium overlying limestone, would not hold water.

When it became clear that the Milk River scheme was a failure, another project was put in hand and was completed in 1917. Water from the Cockpit River, on the east side of the Braziletto Hills, was brought by a low-level canal to a pumping station at Salt River, at the south-east corner of the Hills, where it was lifted seventy feet and discharged into a high-level concrete aqueduct. In this it was conducted westwards to a system of canals connected with the Milk River canal system. The scheme, which was successful and is still in operation, serves to irrigate 4000 acres of sugar-cane in Vere.

In the 1920s various projects to use the water of the Rio Minho were considered, but all were abandoned as impracticable. This river rises in, and at first flows eastwards over, the impervious Cretaceous rocks of the Central Inlier, which lies north of the Mocho Mountains. At Low Ground it turns south and flows through a gorge in Tertiary Limestone. Here the volume of water steadily decreases by percolation, finally disappearing below Longville. From this point to Alley, two miles from the sea, the river is usually dry. When, however, heavy rain falls in the upper catchment area, it quickly becomes a raging, silt-laden torrent.

2. UNDERGROUND WATER RESOURCES

Since the first settlement on the Clarendon Plains by the men of Cromwell's army in 1660 it has been known that small supplies of water for domestic purposes could be obtained from shallow hand-dug wells in the alluvium. The first well to be used for irrigation, which was sunk in 1909, struck a small flow of water at twenty feet, and reached a second very rich aquifer at forty feet. In another well dug in 1912 at Caswell Hill Estate, north of Kemps Hill, no water was obtained from the alluvium but limestone was unexpectedly struck at a depth of only thirty-five feet, and at sixty-five feet an excellent water-supply was obtained. This was the first instance of a large flow of water being obtained from the limestone below the plains.

Geologically the Clarendon Plains have been described by De la Beche (1827, p. 184) and Sawkins (1869, pp. 161, 186); Hill (1899) barely refers to the area and Matley (1924), who was Government Geologist from 1921 to 1924, published little on it. For our knowledge of the geology of the plains we are dependent chiefly on the work of Matley's assistant and successor, Mr. G. M. Stockley (1924, 1925 and several unpublished reports). Recently the Geological Survey of Jamaica has investigated the area (1955, 1956).

As Stockley pointed out, after a study of about 120 wells, the pervious beds of the plains are divided into an upper gravel and a lower limestone series, between which lies a widespread clay horizon, probably of marine origin. This clay separates two different aquifers, of which the upper derives its water from rainfall on the plains themselves, and by seepage from the Rio Minho, while the lower is fed by the rich water resources of the surrounding limestone hills. This lower zone is much the more important, and most of the borehole wells, after penetrating the upper zone with its limited supplies, strike water in large quantities in the limestone. Over most of the area the White Limestone lies at no great distance below ground-level; indeed it breaks through the surface of the alluvium at other places besides Kemps Hill.

Stockley, however, expressed the view that, while a considerable volume of water must pass through a network of solution passages in the limestone beneath the plains, it would be possible for a boring to miss one of these by a matter of inches, so the prospect would have to be faced that for every productive well many unsuccessful ones might have to be drilled. Stockley never had the opportunity to put his theories to the test by making a number of exploratory borings as he wished, for the post of Government Geologist was abolished shortly afterwards, and it fell to others to discover that water in considerable quantities could be obtained, not only from the solution passages, but also from certain water-bearing strata within the limestone itself.

3. THE CATCHMENT AREA

The Manchester Highlands, which lie to the west of the Clarendon Plains, consist of a tilted block of White Limestone probably 1500 feet thick, bounded on the west by the great Spur Tree fault, trending NNW.–SSE., which has raised this side of the plateau to a maximum height of over 3000 feet. Near the centre of the fault scarp, at Nottingham, there is a small inlier of the underlying Cretaceous beds, and from this point the Tertiary Limestone generally dips towards the NE. and E. The Mocho Mountains, which rise to the north of the plains, are another tilted block of White Limestone, dipping towards the S. or SSW., away from the Cretaceous of the Central Inlier.

Beyond the north-west corner of the plains, the Mocho Mountains are separated from the Manchester Highlands by the Williamsfield–Porus trough, which trends NW.–SE. This was described by Matley (1924) as a syncline, but it is probably a zone of intense fissuring and faulting, and should rather be regarded as a graben, towards which the limestone dips from both sides. The Manchester Highlands and the Mocho Mountains are intensely karstified, and almost all the rainfall rapidly disappears in the numerous sink-holes and fissures, and no doubt flows underground in the general direction of the dip. Thus, while much of the groundwater passes directly below the Clarendon Plains, a considerable proportion finds its way to the Williamsfield–Porus trough. Here it moves in the numerous fissures in a south-easterly direction and, while the bulk of it passes below the plains, a certain amount of the water normally issues at the surface below the village of Porus, to form the headwaters of the Milk River.

At St. Toolies, in the north-west corner of the plain, the water-table is near the surface, and after prolonged rain in the mountains, springs burst out at an elevation of 200 feet. Thence the level of the water-table falls rapidly to a height of forty feet above sea-level two miles from the foot of the Manchester Highlands. Beyond this the hydraulic gradient becomes less steep and over a considerable area of the central part of the plain the static level is at sixteen feet above sea-level.

The Braziletto Hills, on the east of the plain, are generally less than 500 feet high, except at their southern end where they attain 810 feet. Their underground flow is mainly towards the east, and they contribute little to the water resources of the Clarendon Plains.

4. THE DEVELOPMENT OF THE GROUNDWATER RESOURCES

As knowledge of the hydrogeological conditions of the Clarendon Plains accumulated, it became increasingly evident that this was an area where large supplies of water for irrigation could be obtained from borehole wells. The United Fruit Company, who had interests in the area, calculated that approximately 16,900,000 gallons of water flowed beneath the alluvium of the plains every hour, exclusive of the water derived from the Rio Minho and from the rain precipitated on the plains themselves. A test of the old limestone well on Caswell Hill proved that it would yield more than 101,000 gallons per hour. Starting in 1929 the Company drilled a series of highly successful wells, and other property-owners followed suit, so that by the beginning of the second world war at least twenty wells had been drilled with most satisfactory results.

After the war the West Indies Sugar Company drilled a large number of wells, but many of these were sunk only into the upper alluvial formation with its limited supply, and before long some of them showed signs of decreasing flow and increasing salinity. In 1949 the Company was able to obtain the services of Mr. G. M. Stockley, now Chief Geologist of Tanganyika Territory, who had reported on the hydrogeology of the Clarendon Plains twenty-five years earlier, and on his recommendation new boreholes were drilled in the limestone formation farther to the north, which yielded a good supply.

Thus the development of Vere and the Rio Minho flood-plain was carried out by private enterprise, but there remained an area of approximately

25,000 acres in the north-western corner of the plain on which a population of at least 2000 lived on small-holdings, and nearly every year suffered acute distress owing to drought. It was to relieve this distress that the Government-sponsored Mid-Clarendon Irrigation Scheme was put into effect. The funds were provided in 1947, and by 1953 thirteen wells had been drilled. A new high-level canal has been cut from St. Toolies eastwards across the plain and over four miles of the old Milk River Canal have been restored. Into both these canals water from the Milk River can be discharged when it is available, as well as water from any or all of the wells in the area when the stream is dry. From both these main canals a number of distributory canals have been cut; the total length of all canals is about thirty-five miles and the area served by the Mid-Clarendon Irrigation Scheme is at present over 12,000 acres. Electric power for pumping is obtained from the 1500 kilowatt power plant installed by the United States army at their war-time base at Vernamfield, which was generously handed over to the Jamaica Government in 1950.

The numerous boreholes that have been drilled in the Clarendon Plains have thrown much light on the topography of the limestone surface beneath the alluvium. South of a line drawn tangentially to the southern margins of the Manchester Highlands, Kemps Hill and the Braziletto Hills the limestone surface has never been reached though wells have been drilled to depths of up to 750 feet. Evidently the line represents a fault, and probably there is another fault along the northern margin of Portland Ridge. The intervening down-faulted belt is known as the Vere Graben.

North of the Round Hill–Braziletto fault the limestone surface generally lies at depths of less that 200 feet beneath the surface. There is a buried channel, however, about two miles wide, stretching diagonally across the plain from north-east to south-west, in which the limestone lies at depths of from 300 to 500 feet below ground-level. It may be tentatively suggested that this buried channel represents a former valley of the Rio Minho formed at a time when the island stood higher or sea-level was lower than it is today, and possibly it is graded to a base-level represented by the buried limestone floor of the Vere Graben.

CONCLUSION

Few Jamaicans realise that since 1929 a major agricultural revolution has taken place in the plains of Clarendon. Many can remember the days when on three-quarters of the area only arid pastures and dense thickets met the eye. In twenty-seven years we have seen the area under cultivation increase from 6000 acres to 35,000 acres, while sugar production has risen from 12,000 tons in 1929 to 87,000 tons in 1953, more than the whole island used to produce before the war. And the main factor that has brought about this revolution has been the discovery in 1929 that large volumes of water could be obtained from borehole wells.

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The authors wish to express their thanks to Messrs. Lloyd M. Adams and Clive O. Adams, who prepared the map shown as Fig. 1.

REFERENCES

De la Beche, H. T. 1827. Remarks on the Geology of Jamaica. *Trans. geol. Soc. Lond., Ser. 2*, **2**, 143–94.

Hill, R. T. 1899. The Geology and Physical Geography of Jamaica. *Bull. Mus. comp. Zool. Harv.*, **34**, 1–256.

Jamaica Geological Survey. 1955. *Annual Report for 1953–4.*

———. 1956. *Annual Report for 1954–5.*

Matley, C. A. 1924. Report by the Government Geologist. *Supplement to the Jamaica Gazette*, **47**.

Sawkins, J. G. 1869. Reports on the Geology of Jamaica. *Mem. geol. Surv. U.K.*

Stockley, G. M. 1924. Hydrology of the Plains of Clarendon. *J. Jamaica agric. Soc.*, **28**, 327–32.

———. 1925. Final Report of the Geological Department. *Supplement to the Jamaica Gazette*, **48**, 23–35.

Taylor, S. A. G. 1955. 'An Account of the Development of the Water Resources of the Clarendon Plains in Jamaica' (in press).

Zans, V. A. 1951. Economic Geology and Mineral Resources of Jamaica. *Geological Survey of Jamaica Bulletin*, No. 1, 41.

———. 1952. Ground-Water Supplies by Borehole Wells. Farmer's Handbook. *Jamaica agric. Soc.*, 207–11.

The Forest Marble Ridge at Rudge, near Beckington, Somerset

by C. E. PERIAM

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ABSTRACT: The stratigraphy and structure is deduced from detailed mapping of the area. A reinterpretation is suggested.

Whereas a single fault throwing down to the north of the ridge at Rudge has been previously demonstrated, detailed mapping suggests that the ridge is a horst feature with the Oldford fault, an extension to the north-east of a fault previously mapped, downthrowing to the south and thus completing the Rudge horst. It is shown that the horst coincides with an anticlinal axis. A similar structure, the Woodstock horst, is briefly referred to.

1. INTRODUCTION

THE AREA DESCRIBED in this paper lies to the south and east of the village of Beckington in east Somerset. It extends from Oldford, near Frome, in Somerset, to North Bradley, near Trowbridge, in Wiltshire, the small village of Rudge sitting astride the boundary between the two counties. The easterly extension of Forest Marble beds in this district forms a ridge of relatively higher ground, which constitutes a marked topographic feature around Rudge. The area is represented on two sheets of the Geological Survey 1-inch Old Series maps; the western part on Sheet 19 (originally surveyed under the direction of De la Beche, with a revised edition published in 1873), and the eastern part on Sheet 14 (1857). Lonsdale (1832, p. 256) referred to the Hinton Sands of Rudge as did Arkell (1933, p. 268), while Woodward (1894, p. 351) described a quarry in the Forest Marble beds. Apart from these passing references no other information is available, and the Geological Survey maps provide the only guide to the structure of the area.

The area was mapped by the Author during the summer of 1954, as part of a survey of the Jurassic rocks of this and adjacent parts of Mid-Wiltshire. The results of this mapping and of subsequent visits are incorporated in this paper (Fig. 1).

2. STRATIGRAPHY

The succession in this district is as follows:

Oxford Clay	
Cornbrash	15 feet (approx.)
Forest Marble	100 feet
Upper Forest Marble	
Hinton Sands	0–30 feet
Lower Forest Marble	
Fuller's Earth	40 feet
Inferior Oolite	

The Inferior Oolite has a small outcrop at Oldford, where tributary streams of the River Frome have cut through the Fuller's Earth. The Oolite is well exposed in an old quarry at Bonnyleigh House (31/790505) noted by Richardson (1909, p. 219), but now becoming overgrown.

The succeeding Fuller's Earth occupies the lower slopes of Bonnyleigh Hill and runs up into Winkle Bottom, being bounded to the south by the Oldford fault. It is nowhere well exposed, but the usual Fuller's Earth Rock fossils are plentiful in banks, streams and gardens. A short distance to the south-west, at Whatley, the Fuller's Earth has recently been investigated (Sylvester-Bradley and Hodson, 1957). They subdivide twenty feet of Fuller's Earth Rock into *Ornithella* Beds below and *Rugitela* Beds above, and comment, 'Although *Ostrea acuminata* is also doubtfully recorded in the *Rugitela* Beds, associated with *O. matisconensis*, the latter is overwhelmingly predominant there and does not occur in the Lower Fuller's Earth Clay. . . . The *Ornithella* Beds are characterised by the abundance of species of that genus to the virtual exclusion of *Rugitela* whereas not a single specimen of *Ornithella* has been found in the *Rugitela* Beds.'

The faunal assemblages of the two subdivisions agree with those of the 'true' Fuller's Earth Rock and the 'upper' rock or *Wattonensis* Bed recognised by Kellaway & Wilson (1941) in the Sherborne area.

By comparison with these areas, the fauna of the Fuller's Earth at Oldford displays a certain peculiarity. Of the brachiopods, species of *Ornithella* are most abundant, rivalled by a number of species of *Wattonithyris*, while *Rugitela* is comparatively rare. This suggests a correlation with the *Ornithella* Beds of Whatley and the 'true' Fuller's Earth Rock of Sherborne, although the relative abundance and number of species of *Wattonithyris* is greater than in the *Ornithella* Beds at Whatley. The oysters, however, tell a different story. *Ostrea* (*Catinula*) *matisconensis* is abundant, while *Ostrea* (*Liostrea*) *acuminata* is represented in my collection only by a single specimen. It would appear then, that the two rock bands and their characteristic faunas are to some extent 'mixed' in a single bed, too thin for them to be separated in the field. Richardson (1909, p. 219) saw four feet of Fuller's Earth Rock at Bonnyleigh House Quarry, which he described as 'clay, with bands of pale earthy limestone'. Lack of exposures prevents an accurate estimation of the thickness, but it seems unlikely to be much more than that noted by Richardson.

The Forest Marble is largely a clay formation with variable and impersistent beds of shelly limestone, and in this district includes the Hinton Sands. The thickness and position of the Hinton Sands is found to vary considerably, but they do provide a means of making a mappable threefold lithological subdivision into lower and upper groups of clays and shelly limestones, separated by sand and sandstone. The variability of the formation is well illustrated in this district. The Hinton Sands are strongly developed on the hill near Rudge where they are still exposed in a number of old quarries. The sandstones were also seen to be well developed in a trench near Dadley Lane (31/816515). Yet in another trench between these two points, not half a mile apart, the Hinton Sands have practically disappeared. They appear to be replaced laterally by shelly limestones and clay with only a few sandstone bands persisting.

The Lower Forest Marble is predominantly clay, although where the base is seen at Bonnyleigh Hill shelly limestones are developed. The main interest in the outcrop on Rudge Hill lies in the discovery of an ammonite, a very rare occurrence in the Forest Marble. The specimen has been identified by Dr. Arkell as a new species of *Polyplectites*. This is the first *Polyplectites* known from the British Bathonian, and so is of little help in correlation, although Dr. Arkell informs me that the genus is uncommon on the Continent in the Middle and Upper Bathonian. The lithology at this locality is unlike the typical comminuted 'marble' of this area, consisting as it does of a conglomeration of whole and partly broken shells, mostly oysters, but including rhynchonellids and gasteropods.

The outcrop of the Hinton Sands is well marked in the middle valley slopes around Bonnyleigh Hill, but to the south and east is poorly developed and impersistent. Sand again becomes widespread around Rudge where old quarries expose brown sand with bands and doggers (Lonsdale's 'pot-lids') of calcareous sandstone.

The Upper Forest Marble is largely clay, although the presence of thick bands of shelly limestone give it a wide outcrop around Rudge. These beds are exposed in a number of old quarries near the village. Identifiable fossils are rare, but one locality yielded some brachial valves agreeing in size and shape with the type of *Epithyris marmorea* (Oppel) figured by Davidson from Corsham, where they are abundant and well preserved. To the north-east the topography reflects the outcrop pattern, for as the Forest Marble dies out, so the ridge which it forms through Rudge flattens out towards North Bradley.

The Cornbrash of this area is restricted to the Lower Cornbrash, the upper part being absent north of Frome. The zonal ammonite, *Clydoniceras discus*, was found in the trench near Rudge Lane (31/812524). Although occupying a wide outcrop, the deposit is fairly thin, and consists of rubbly limestone with a mixed *intermedia* and *obovata* fauna. It is very fossiliferous, the most common forms being *Ornithella obovata* (J. Sowerby), *Cererithyris intermedia* (J. Sowerby), *Meleagrinella echinata* (W. Smith), *Anisocardia minima* (J. Sowerby), *Protocardia buckmani* (Morris & Lycett), *Gresslya peregrina* (Phillips), *Pleuromya uniformis* (J. Sowerby), *Ceratomya concentrica* (J. de C. Sowerby), *Pholadomya deltoidea* (J. Sowerby), and *Homomya gibbosa* (J. Sowerby).

The ridge is flanked by Oxford Clay which occupies the lower ground. Exposures are rare and no evidence of Kellaways Beds has been seen.

3. STRUCTURE

The ridge of higher ground running in a north-easterly direction from near Standerwick almost to North Bradley, is shown on the Geological Survey 1-inch Old Series Sheets 14 and 19 to be composed of Forest Marble, thrown up by a fault running along the northern side of the ridge, with a normal succession to the south. Detailed mapping suggested that another interpretation was necessary, for two main reasons.

(a) From the Warminster road near Winkle Bottom (31/808509) to Brokerswood (31/834521), a distance of one mile, no evidence of Cornbrash was found. The Geological Survey (Old Series) map shows the Cornbrash as a very narrow strip along the south side of the ridge although, both from the dip and the southerly slope of the ground, one would expect a considerable width of outcrop.

(b) South of Bonnyleigh Hill the Old Series map shows Fuller's Earth faulted against Forest Marble, with downthrow to the south. This fault is shown as a continuation of the one which forms the northern boundary of the Forest Marble ridge to the north-east, where the downthrow is to the north. This requires a 'hinge' in the vicinity of Winkle Bottom, but this is difficult to fit in with the mapping.

It is now suggested that the southerly throwing fault at Oldford is continued to the north-east along the southern side of Rudge Hill, where it cuts out Cornbrash and brings Upper Forest Marble against Oxford Clay. It is proposed to call this the Oldford fault. There is no doubt that a fault with northerly downthrow exists along the northern side of the hill, and it is proposed to call this the Rudge fault. The ridge is thus the result of two parallel faults with opposite outward throw, and the whole structure is referred to as the Rudge Horst (Fig. 2). This view was arrived at during the mapping of the area in the summer of 1954. In the past year extensive trenching operations have been carried out on Rudge Hill which have confirmed this conclusion. Trenches on the north side of the ridge enabled the position of the Rudge fault to be fixed at two points. More recently a further trench on the south side has proved the presence of the postulated fault there.

The Oldford fault enters the area just north of Oldford, where the throw is at least sixty feet. Fuller's Earth Rock has been proved at Windsbatch (31/792503), so that here the Upper Fuller's Earth and most of the Forest Marble have been cut out. This amount of displacement continues towards Rudge, for in the trench mentioned above (31/825516) a fragment of a *jason* Zone ammonite was found immediately south of the line of the fault, where Oxford Clay was seen against Upper Forest Marble. North-east of Brokerswood the Forest Marble and Cornbrash are in normal succession, and here the fault brings Cornbrash against Oxford Clay before passing wholly into the clay outcrop. However, the throw does not appear to be decreasing. A pipe trench only 300 yards from the Cornbrash–Oxford Clay junction yielded numbers of *Gryphaea lituola*, indicative of Middle Oxford Clay (Arkell, 1947, p. 68). Beyond this point the Oldford fault cannot be traced in the field.

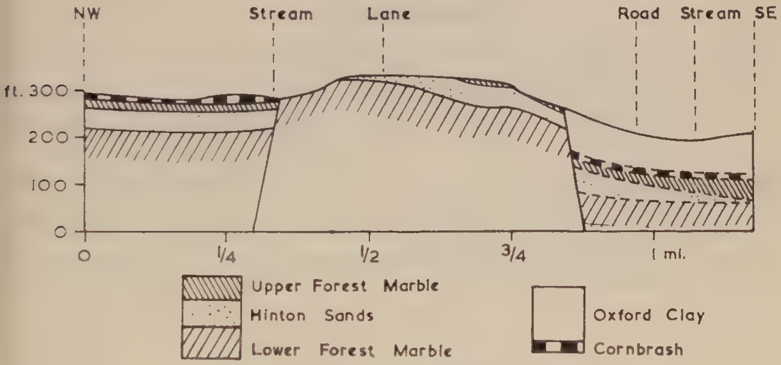

Fig. 2. Section through Rudge Hill

The Rudge fault branches off the Oldford fault near Winkle Bottom, and can be traced for three and a half miles as far as North Bradley. Along the north of Rudge Hill Cornbrash is brought against Lower Forest Marble, giving a throw of sixty feet or more. East of Rudge the throw gradually decreases until the fault feathers out near North Bradley.

CONCLUSION

The dip of the beds on either side of Rudge Hill, and that of adjacent areas, gives a clue to the formation of the Rudge Horst. The dips show that the horst coincides with an anticlinal axis. It seems probable that the structure was due to a gentle fold, faulted on both limbs. A similar structure is to be found in the Woodstock Horst (Arkell, 1947, p. 143), which, however, is on a smaller scale, and does not have the marked topographic effect of the structure here described.

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REFERENCES

Arkell, W. J. 1933. *The Jurassic System in Great Britain.* Oxford.

———. 1947. *The Geology of Oxford.* Oxford.

Kellaway, G. A. & V. Wilson. 1941. An outline of the geology of Yeovil, Sherborne and Sparkford Vale. *Proc. Geol. Ass., Lond.*, **52**, 131–74.

Lonsdale, W. 1832. On the Oolitic district of Bath. *Trans. geol. Soc. Lond., Ser. 2,* **3**, 241–76.

Richardson, L. 1909. Excursion to the Frome district, Somerset. *Proc. Geol. Ass., Lond.*, **21**, 209–28.

Sylvester-Bradley, P. C. & F. Hodson. 1957. The Fuller's Earth of Whatley, Somerset. *Geol. Mag.*, **94**, 312–25.

Woodward, H. B. 1894. The Jurassic rocks of Britain. IV. The Lower Oolitic rocks of England. *Mem. geol. Surv. U.K.*

Some Aspects of the Glacial and Post-Glacial History of the Lower Goyt Valley, Cheshire

by R. J. RICE

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ABSTRACT: In the valley of the River Goyt between New Mills and Stockport there is a conspicuous alternation of gorges cut through solid rock and flood-plains eroded from glacial and fluvio-glacial drift. Examination of the relationship between the drift and the solid rock suggests that most if not all the gorges occur at points where the river, instead of re-excavating its former valley, has been superimposed from drift on to the old valley spurs. The resulting contrasts in the nature of the river bed have exerted a powerful influence on the upstream migration of post-glacial knickpoints.

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1. INTRODUCTION

THE RIVER GOYT rises near the Cat and Fiddle Inn on the Cheshire–Derbyshire boundary. Flowing for the first nine miles northwards to New Mills, it then turns westwards to Disley but soon resumes its northerly direction until joined by the Etherow. The combined streams then run westwards to join the Thame in the centre of Stockport. It is the aim of the present paper to describe the effect of the glaciation on that section of the valley between New Mills and Stockport. Where an account of the distribution of glacial drift is given it is based almost entirely upon personal observation since information from other sources, although used where available, is insufficient to provide more than a little supplementary evidence.

Between New Mills and Stockport the valley has characteristically a flat floor cut across glacial material and veneered with alluvial deposits. Above this rise steep slopes, usually with a thin cover of boulder-clay extending up to a feather edge, but sometimes almost drift-free. Before examining the distribution of drift in relation to the present valley form it is necessary to outline what is known of the glacial history of the region.

2. THE GLACIAL HISTORY OF THE REGION

It is now generally agreed that the South Pennines have been subjected to at least two major glacial phases, the first of which saw all but the highest peaks buried, while during the second the Irish Sea ice was banked against the western flank of the upland. Although the provenance of the ice is indicated by numerous erratics from Lake District sites, the above skeletal chronology has not been greatly elaborated. Jowett and Charlesworth (1929) have traced the limit of the later glaciation and they suggest that the ice at its maximum just succeeded in passing through the col at Dove Holes, Derbyshire. In addition they draw attention to a great kame-moraine in the Goyt and Todd Valleys near Whaley Bridge which probably represents a major stillstand in the final retreat of the ice.

Whilst the dual glaciation can be demonstrated from consideration of a wider area it is difficult to prove from the very variable deposits in the Goyt Valley itself. More detailed work on the drift of the neighbouring Cheshire Plain will be necessary before the complete glacial history is finally unravelled. One may, however, attempt a reconstruction of the conditions left by the retreat of the ice from the New Mills–Stockport area. Above an altitude of about 1400 feet the ground is almost free of foreign erratics, while from 1400 feet down to a somewhat variable level, but in the neighbourhood of 1000 feet, the hills are littered with numerous boulders of both local and foreign origin. Below 1000 feet there is a much more continuous deposit of boulder-clay, sand and gravel, thickest in the valleys and thinning to a feather edge on the higher hillsides. After withdrawal of the ice normal stream drainage was resumed, with the results described below.

3. THE PRE- AND POST-GLACIAL COURSES OF THE RIVER GOYT

Some idea of the thickness of drift which the lower Goyt has removed since the end of the glaciation may be obtained from the amount of boulder-clay remaining along the valley sides. Near New Mills the river probably began to flow some thirty feet above its present level, while near Marple Bridge it began some seventy feet above it. Drift of such thickness would clearly be capable of masking the form of the pre-glacial valley and to a lesser extent of actually obscuring its position. As irregularities in the initial boulder-clay surface would determine the river course, there was no guarantee that the new river would follow exactly the line of the buried channel; certain features of the modern valley can be attributed to differences between the old and new courses of the river.

Reference to the water and contour map (Fig. 1) reveals that the valley below New Mills consists of sections with broad, river-cut floor alternating with comparatively short sections of gorge. These gorges occur at New Mills, Hague Bar, Strawberry Hill, Marple Bridge, Ley Hey Park, Offerton and Stockport, and each merits detailed examination.

(a) **The New Mills Gorge** (Fig. 2A)

Above New Mills the Goyt meanders across a flood-plain some 200 yards broad, but at the town it passes through a narrow fifty-foot gorge. One wall of the gorge is formed by the rocky lower slopes of the hillside on which New Mills stands, the other by bedrock outcropping at the distal end of a long spur extending north-eastwards from Newtown. In their account of the glaciation Jowett & Charlesworth (1929, p. 324) imply that the central portion of this spur consists of drift, and this was confirmed during a re-examination of the ground. The limit of the drift is apparently defined by outcrops of solid rock at New Mills railway station and at the distal end of the spur where the actual junction between the boulder-clay and solid rock may be seen sloping south-westwards away from the river. It seems that the pre-glacial course of the Goyt (approximately delimited by the dotted lines in Fig. 2A) lay 250 yards south-west of the gorge. On both banks of the river were strong grit ribs subsequently buried under boulder-clay. Post-glacial superimposition on to the resistant grit has so severely restricted lateral corrasion as to produce a gorge.

A boring on the flood-plain at Grove Mill (33/996851) sheds further light on the pre-glacial valley. The bore record (Stephens, 1929, p. 108) shows sixty-one feet of mixed boulder-clay, sand and gravel resting on bedrock. This proves that the river has removed only a small fraction of the total drift infilling, and that it is still flowing some sixty feet higher than its pre-glacial ancestor. The drift exposed on the Newtown spur must be regarded as only the upper portion of a deep wedge lying in what is probably a steep-sided and comparatively narrow-floored valley.

(b) **The Hague Bar Gorge** (Fig. 2B)

For a mile below New Mills the Goyt winds across a broad flood-plain, undercutting bluffs of boulder-clay where it impinges against the valley side and in some cases exposing the solid rock beneath. At Hague Bar the flood-plain narrows and a long, flat-topped spur shown on the 1-inch Geological Survey map as consisting entirely of shale projects from the right side of the valley. Whilst the feature certainly terminates in a thirty-foot cliff of shale, a study of the exposures on the remainder of the spur revealed sandy boulder-clay but no bedrock. The circumstances are very similar to those at New Mills and the river has apparently entrenched itself into another valley spur. This interpretation is supported by an impressive river cliff on the left bank which represents a section through the severed spur, and by a boring close to the foot of the cliff which shows only six feet of alluvial mud overlying bedrock.

(c) The Strawberry Hill Gorge (Fig. 2C)

This reproduces almost exactly the conditions at Hague Bar. There is again the long projecting spur, in this case shown on the Geological Survey map as composed mainly of boulder-clay; the irregular surface of its central portion probably results from the slumping of unconsolidated drift. Solid rock on the other hand is clearly exposed in both banks of the river.

The suggestion that the distinctive form of the Goyt Valley derives from the occasional superimposition of the river from boulder-clay on to bedrock is an alternative explanation to that advanced by Jowett & Charlesworth (1929, p. 324). In the opinion of the latter authors the drift at New Mills and Hague Bar constitutes stadial moraines, and that at Strawberry Hill might be likewise interpreted. However, the existence of glacial deposits of similar type in an almost continuous shelf along the valley sides favours the idea of a once complete infilling, while the evidence of the Grove Mill bore proves that the material exposed in the spurs is but a small part of a much deeper wedge. The confining of the river at the three isolated points where it became entrenched in solid rock restrained the swinging of meanders and so reduced the chances of escape from the gorges by means of cut-offs.

(d) The Marple Bridge Gorge (Fig. 2D)

Twelve hundred yards above Marple Bridge the Goyt again swings across to the western side of its valley and enters a gorge. However, instead of merely side-stepping a long spur barring its path, the river continues as far as Marple Bridge confined between steep rock walls. Whilst the left bank wall rises almost sheer more than 100 feet, that on the right bank rises to less than fifty feet and is breached by the incoming of two small tributaries. The similarity with conditions at New Mills, Hague Bar and Strawberry Hill indicates the likelihood of a further buried channel immediately east of the gorge. Other considerations lend support to such a hypothesis. At Grove Mill borehole the height of the bedrock floor of the valley is no more than 335 feet O.D., and at Stockport only 150 feet. Although care must be taken in interpreting the borehole evidence because of possible overdeepening by ice or meltwater under hydrostatic pressure, these figures probably represent the altitude at which the Goyt flowed prior to deposition of the drift. An estimate of the corresponding altitude at Marple Bridge, based upon the likely river gradient, is 250 feet O.D. Today, however, the Goyt flows on bedrock at 280 feet, and this is easily explained only if there is a buried channel parallel to the Goyt but a few hundred yards farther east. The presence of the rock gorge precludes the other explanation, that the river has merely strayed from the central zone of drift on to the adjacent Coal Measures.

Any buried channel on the right bank would commence by cutting across the interfluve between the Goyt and Mellor Brook. Examination of the gulleys scored by small rivulets in the irregular southern face of the interfluve reveals nothing but sandy boulder-clay. More instructive are the exposures in the valley and bed of Mellor Brook for they limit considerably the possible positions of the channel. The western wall is defined by the ridge of bedrock breached by the brook just before its confluence with the Goyt, the eastern wall by an outcrop of bedrock just below Cataract Bridge (33/970888). The intervening 300 yards of the Mellor Brook Valley seems to be entirely in boulder-clay. A similar study of Clough Mill Valley discloses solid rock near the confluence of the stream with the Goyt, then some 350 yards with relatively clean sections in which only drift is seen, and higher upstream further outcrops of solid rock. More solid rock in the banks of the Goyt requires that the buried channel join the main valley at least quarter of a mile below Marple Bridge.

The evidence is far from conclusive—sited on the presumably narrow ridge of Coal Measures between the postulated channel and the Goyt is a disused mine—but there are none-the-less cogent arguments for supposing there to be a channel. In the absence of boreholes it would be unwise to state the case more strongly than that.

(e) The Ley Hey Park Gorge (Fig. 2E)

Perhaps the most striking feature in the lower Goyt Valley is the great incised meander developed by the river just after it is joined by the Etherow. Inasmuch as the core of the meander is composed entirely of solid rock it differs from those spurs associated with the gorges higher upstream. However, the inadequacy of the Geological Survey 1-inch map (Old Series, No. LXXXI N.W.), necessitated a remapping of the superficial deposits and this showed the difference to be one of degree rather than type. The available evidence undoubtedly points to the existence of a buried pre-glacial valley running north of the present position of the Goyt.

Thinly covering the plateau into which the Goyt is entrenched is a variable but almost continuous layer of boulder-clay. The writer believes that this obscures for most of its distance a gravel-filled channel running from the western side of the lower Etherow Valley to the Goyt Valley just below Marple Dale farm. Because of the boulder-clay capping, exposures of the gravel are confined to the river cliffs at the upper and lower ends of the channel. The exposures at the lower end are particularly clean and the boundary between drift and solid may easily be traced from the eastern end of Hydebank Tunnel (33/948903) down to the water's edge. Beneath the capping of boulder-clay there are over fifty feet of well-bedded gravel with occasional lenses of sand. Where best exposed the gravel is composed almost entirely of flat pebbles derived from the Upper Carboniferous grits and sandstones. The pebbles all lie with their axes pointing downstream, i.e. westwards, at angles generally between ten and twenty degrees from the horizontal, and were probably deposited by a torrential river following the pre-glacial course of the Goyt. Careful searching, however, brought to light a few fragments of Eskdale granite and Lake District andesite, the presence of which indicates the inter-glacial origin of the gravel. One might expect to find similar material where the Etherow is undercutting the upstream end of the channel. Unfortunately the heavily vegetated slope is almost entirely covered by downwash and only towards the top, where fine sand predominates, can fresh surfaces be seen.

To trace the northern edge of the channel is more difficult. Bedrock exposed in river bluffs north of the Chadkirk Works disappears eastwards under a cover of boulder-clay. No further outcrops could be found in the valley of the small stream joining the Goyt at Chadkirk, although at one point the drift contained so much shale as to suggest close proximity to solid rock. East of Romiley the almost continuous boulder-clay cover obscures all traces of the channel wall.

The abandonment of the channel may be ascribed to the post-glacial superimposition of the Ley Hey Park meander. Turncliff Wood (33/944896), half a mile farther downstream, may also be ascribed to such superimposition. Rising abruptly more than 100 feet above the valley floor, this circular knoll is composed almost entirely of shale and at one time must have formed the distal end of a long spur projecting from the northern side of the Goyt Valley. The spur would be closely analogous to those at Hague Bar and Strawberry Hill. At Turncliff Wood, however, the river has escaped from its gorge by means of a cut-off breaching the drift-filled central portion of the spur.

(f) The Offerton Gorge (Fig. 2F)

In some ways this is the most puzzling of the rocky gorges through which the lower Goyt flows, since it is apparently situated along the median line of the valley. The other gorges are so offset to one side or other that the probable position of the associated buried channel is obvious; in the case of the Offerton gorge this is not so. On the northern side exposures are rare and the valley form (admittedly a doubtful criterion) does not suggest the existence of a channel. Certain features on the southern side might, however, be attributed to an ancient throughway filled with drift. The most striking is the scooping out of what would be the upstream end of the channel by a former loop of the Goyt. This loop (roughly delimited by the 200-foot contour in Fig. 1) has since been destroyed by a cut-off, but examination of the surviving river-cliff fails to reveal any sign of bedrock. The relationship between drift and solid is also critical in the Poise Brook Valley which runs athwart the line of the channel. Although Triassic sandstone is exposed at intervals up to two hundred and fifty yards from the Goyt, higher up the tributary outcrops of boulder-clay are found in the valley floor. There is undoubtedly a great deal of glacial material in the vicinity of Offerton and there is the danger that downwash may be obscuring the true nature of the valley-sides. However, the writer's belief that the disappearance of bedrock is due to more fundamental causes is strengthened by the records of a number of bores sunk on the Offerton spur to test the thickness of the drift. The deepest penetrated to a depth of fifty feet without striking bedrock, and although the level reached is above that of the Goyt it is considerably below that of the bedrock at the lips of the gorge in which the Goyt is flowing. This shows that the sub-glacial surface falls in height south of the river and lends strong support to the idea of a drift-filled channel.

It is difficult to determine the point at which this channel rejoins the present Goyt Valley. At water level, close to the confluence of Poise Brook, are relatively fresh sections of red sandstone, but 300 yards downstream corresponding exposures consist of well-bedded glacial gravel. For 350 yards below this are heavily vegetated and almost inaccessible slopes but it is thought that bedrock is entirely absent. This could mark the position of the downstream end of the channel. An alternative position is at Woodlands where the Goyt has cut a remarkable niche (approximately delimited by the 200-foot contour in Fig. 1) in an otherwise continuous river-cliff. Although it is bounded by two bastions of Triassic sandstone, the niche seems to have been excavated from drift and may be analogous to the feature eroded by the abandoned meander-loop at the upstream end of the channel.

(g) The Stockport Gorge (Fig. 2G)

Below the Offerton gorge where the relatively weak Permo-Triassic rocks have been unable to restrict meandering with the same success as the Coal Measures and Millstone Grit higher upstream, the Goyt flood-plain has been eroded quite freely across both drift and solid, and the form of the pre-glacial valley largely erased. However, a short distance above Stockport, Messrs. Cantrell & Cochrane have sunk a bore (33/911912) passing through twenty-seven feet of drift before striking bedrock, indicating that the river is still above the level of a pre- or inter-glacial ancestor. It is therefore surprising to find twenty-five-foot cliffs of Permian sandstone and a river bed of solid rock in the eastern suburbs of Stockport. The most satisfactory explanation appears to be that the pre-glacial Goyt joined the Thame about a mile north-east of their modern confluence, and that the present course of the Goyt through Stockport is of later origin. This interpretation requires a further buried channel cutting across the narrow spur which now separates the Goyt and Thame Valleys. A bedrock exposure close to the north-western extremity of the great meander in the Goyt above Stockport considerably limits the possible positions of such a channel. In Fig. 1 the writer shows that position which, after field examination, he considers the most probable.

If this explanation of the Stockport gorge is correct, each distinctive narrowing of the lower Goyt Valley is capable of the same explanation. At first sight it might seem unlikely that a deeply entrenched valley like that of the lower Goyt should have been marked by a depression so shallow as to permit the river to deviate from its pre-glacial course at seven points in twelve miles. However, it is probable that the difference in height between the valley floor and surrounding plateau surface was greatly reduced during the Pleistocene period by stream-deposited gravel, as, for example, at Ley Hey Park, so that it was much easier for the final capping of boulder-clay to mask the exact position of the pre-glacial valley.

4. THE POST-GLACIAL TERRACES OF THE LOWER GOYT VALLEY

Since the Goyt began to flow on the surface left by the final retreat of the ice, it has meandered freely in the reaches between the gorges. Its history, however, has not been one of continuous downcutting, but rather of successive periods of stability separated by minor rejuvenations. This is attested by the presence on the floor of the valley of a series of delicately chiselled terraces, generally cut across glacial drift but sometimes transgressing on to the less resistant of the solid rocks. Five periods of stability have been detected, each being represented by a section of flood-plain which, when dissected by the ensuing rejuvenation head, continues downstream as a series of elevated terrace fragments (Figs. 3 and 4). For the sake of convenience the periods of stability have been numbered from 1 to 5 in chronological order.

Although at New Mills the Goyt plunges through a deep gorge, immediately above and below that town it meanders sluggishly across a broad flood-plain cut from the glacial infill. In such circumstances care must be exercised to distinguish between two separate erosion stages and immature one-cycle development when profile irregularities resulting from differing rock types have not been smoothed out and when comparatively broad valley floors have been cut only in the non-resistant strata. In the former case paired terraces would probably be present below the rock-bar, while in the latter case unpaired terraces eroded during 'restrained downcutting' might be expected above the rock-bar (especially when it is remembered that the Goyt is incised fifty feet into resistant rock). At New Mills the evidence is not conclusive, but the relatively simple valley form above the town and a few small terrace fragments (Stage 1) below it, now standing some fifteen feet above normal river level, favours a two-stage interpretation.

Below New Mills the flood-plain of Stage 2, 300 yards broad and some six feet above mean river level, bears testimony to the meandering of the Goyt. Although narrower, the flood-plain is continuous through the Hague Bar gorge where the shale has not proved sufficiently resistant to prevent a certain amount of lateral erosion. At Strawberry Hill, on the other hand, the river was superimposed on grit and the flood-plain disappears entirely. Between Strawberry Hill and Marple Bridge the natural valley form has been artificially modified and the course of the Goyt diverted (Unwin *et al.*, 1924, p. 162), yet it is still clear that most of the wide expanse of level ground also belongs to Stage 2. However, it no longer constitutes the flood-plain since the river has incised itself to a depth of fourteen feet and begun eroding laterally at this lower level. Thus it appears that a knickpoint has, in recent geological time, passed rapidly from Marple Bridge to Strawberry Hill and is now held on the resistant outcrop at the latter point.

The number and height relationship of the terraces between Marple Bridge and Ley Hey Park indicates that a further knickpoint is held in the Marple Bridge gorge. The Stage 2 terrace provides a further, if minor, example of cut-off by the Goyt after superimposition on to bedrock (see Fig. 3). A short distance below the Goyt–Etherow confluence is an isolated mound with shale core which, during Stage 2, formed part of the flood-plain. After rejuvenation the river was trapped in bedrock between the mound and the left wall of the valley, but escaped by means of a cut-off and left a replica in miniature of Turncliff Wood.

Although the Ley Hey Park gorge breaks the continuity of the terraces they are again well developed around Marple Dale. Correlation with the succession above the gorge suggests that during each phase of stability the river maintained an almost constant gradient from the Etherow confluence to Marple Dale. In conflict with this simple pattern is an abnormally steep terrace fragment on the distal end of the Ley Hey Park meander core (see Fig. 4). The product of powerful lateral erosion, yet associated with a relatively steep river gradient, this feature probably results from an increase in the radius of the meander while a knickpoint was being held on the bedrock outcrop a short distance higher upstream. The writer knows of no reference to similar features elsewhere, and believes it likely that they are restricted to streams with incised or ingrown meanders.

The Goyt passed round the southern side of Turncliff Wood during Stages 2 and 3, but abandoned this course at the end of the latter stage when it rediscovered its drift-filled pre-glacial valley. The ensuing period of stability (Stage 4) saw the Goyt and a small right bank tributary cut a new valley floor which attained a width of almost 600 yards near Chadkirk. This was later converted into a very extensive terrace by the passage upstream of yet another knickpoint now held on the solid rock outcrop at Ley Hey Park. Stage 5, of which this knickpoint was a precursor, is represented by a flood-plain of variable width traceable down to Stockport but disappearing entirely in the Stockport and Offerton gorges. In the latter gorge the fourth terrace is also absent and it appears that even by the time the second terrace was being cut the Goyt was feeling the restraining influence of the rock spur into which it is incised. Between Offerton and Stockport the third, fourth and fifth stages are all well represented, although in Stockport itself the river is bordered by the prominent terrace eroded from bedrock during the fourth stage.

From the above summary it is clear that there have been at least four and probably five stable phases in the post-glacial evolution of the Goyt. During Stages 2, 3 and 4 the Thame–Goyt confluence stood at heights of approximately 170, 155 and 140 feet. Precise dating within the area studied is not possible, but correlation with stages recognised by O. T. Jones (1926) in a paper on the Mersey Valley sheds some light on this subject. Jones claimed that there were in the Mersey Valley three elevated terraces which he called, in descending order, the Didsbury and the Middle (two) Terraces. From their height above the flood-plain a tentative correlation with Stages 2, 3 and 4 in the Goyt Valley may be made. Jones dated the Middle Terraces as post-Submerged Forest period, and if this is correct, Stages 3 and 4 are probably of the same age. Until investigation of a much wider area is made dating can proceed no further.

CONCLUSION

The River Goyt, commencing to flow on the surface left by the final withdrawal of ice, did not follow exactly its pre-glacial course. As a consequence it became superimposed on a number of bedrock spurs, the result of which is clearly visible in the landscape today. In addition the presence of resistant bedrock outcrops at intervals along the course of the river has been a controlling influence in the rate of knickpoint migration. Today the four knickpoints on the lower Goyt are all held at rock-bars where they cause a considerably steepening of the thalweg. At New Mills the flood-plain commences immediately below this steepening, but elsewhere there appears to be a time-lag between the passage of the knickpoint and the cutting of the flood-plain. This is probably a reflection of the speed with which knickpoints cut through the drift between the rock-bars.

Such has been the history of one of the streams draining from the Pennines into the Mersey estuary. Similar features undoubtedly characterise the rest of those streams and the writer is indebted to Mr. H. B. Rodgers of Manchester University for drawing his attention to comparable occurrences in the valley of the Etherow. It may also be noted that on the New Series 1-inch Geological Sheet No. 76 (Drift) there are written through a boulder-clay spur south of Ramsbottom the words 'Preglacial course of the River Irwell'. Only when all these valleys have been investigated in detail will the complete post-glacial history of the Manchester region be decipherable.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to the Manchester, Newcastle and London officers of H.M. Geological Survey for the information and help which they have given him. He is also indebted to the Stockport Gravel Company for details of the boreholes sunk at Offerton.

REFERENCES

JONES, O. T. 1926. The origin of the Manchester Plain. *J. Manchr. geogr. Soc.*, **39–40,** 106.

JOWETT, A. & J. K. CHARLESWORTH. 1929. The glacial geology of the Derbyshire Dome and western slopes of the South Pennines. *Quart. J. geol. Soc. Lond.*, **85,** 307.

STEPHENS, J. V. 1929. Wells and springs of Derbyshire. *Mem. geol. Surv. U.K.*

UNWIN, G., A. HULME & G. TAYLOR. 1924. *Samuel Oldknow and the Arkwrights.* Manchester.

Field Meeting at Pewsey Vale and Devizes District

31 August to 2 September 1956

Report by the Director: R. S. BARRON

Received 3 November 1956

SATURDAY, 1 SEPTEMBER, was mainly devoted to the rocks exposed at the west end of the Vale of Pewsey. A section of Upper Greensand in a typical cutting near Erlstoke (31/959537) was first inspected and specimens of *Exogyra conica* were collected. About 200 yards south of the village of Tinhead a clearance of undergrowth had been made so that the junction of the Upper Greensand and Lower Chalk could be clearly seen. Near this exposure is a good example of a dry chalk valley with a level floor, and sides that show the parallel ridges formed by solifluction. Some discussion took place on the details and climatic conditions required for such structures.

The road from Tinhead to Devizes passes over strata ranging from Kimmeridge Clay to Upper Greensand (Purbeck and Wealden excluded). From a suitable viewpoint (31/988563) on a small outcrop of Lower Greensand the Director was able to point out the main features of Pewsey Vale: that it has no river flowing down its length, that it is a small plain bordered by escarpments first of Upper Greensand and then of Middle Chalk. The plain is formed mainly of Gault, characterised by flat pasture fields, and Portland Beds that form slightly undulating ground through which a small stream has cut down to the Kimmeridge Clay. About a quarter of a mile east of the village of Worton an exposure of Portland Sands was examined in a road cutting.

By permission of the manager of the Devizes Brick and Tile Company the large pit in the Gault Clay at Caen Hill (31/980613) west of Devizes was visited. Members were able to see the considerable variety of bricks that can be produced. The Director explained that whereas the Gault Clay in other areas yields a yellow coloured brick, that at Devizes produces a red brick. Ammonites occur in two bands, one near the base of the pit and the other about ten feet higher. It is barely possible to find specimens in the actual face but members were able to gather species of *Hoplites* from the large area of clay that is left exposed to the weather before it is taken away to the kilns.

After lunch at 'The George and Dragon', Potterne, the party moved to the small exposure of Portland Beds near Crookwood Farm (41/015580). A small stream has cut down about three feet below the level of the fields and in the banks are about two feet of sand above a rubbly glauconitic limestone. Several fossils were found and comparison was made with the Portland Beds of Swindon. After crossing the Western Region railway line the road to Urchfont was left in order to view the Upper Greensand escarpment that lies between Three Graves (41/023576) and the railway line. A number of fossils, including ammonites, have been obtained from the soft sandstone of this area. South of Urchfont runs a lane that formerly was noted for its exposure of Chloritic Marl, but the banks are now overgrown. After a brief inspection the party returned to West Lavington for tea.

About 500 yards south-east of West Lavington church is another exposure (41/010531) of the junction of Upper Greensand and Lower Chalk. The change from Glauconitic sand to a Chalk marl can be seen to take place in a two feet thickness of rock. By travelling up the hill the whole thickness of about 200 feet of Lower Chalk is traversed. A large quarry, formerly used for obtaining the hard Melbourn Rock, was reached at the top of the escarpment. The Director was able to point out the other exposures of Melbourn Rock on the opposite hill-side. The height of this band on the west side of the road is about 100 feet lower than on the east side. A fault probably exists approximately along the line of the road. By permission of Mr. M. Holloway the party walked through part of the valley known as 'The Warren'. At the head of this valley vigorous springs flow from the Lower Chalk. Beside a pool (41/006524) members were able to find the zonal ammonite *Schloenbachia varians*.

Sunday, 2 September

The itinerary for this day covered the Upper Jurassic rocks west of Devizes. From a meeting-point below the Westbury White Horse the party moved to Dilton Marsh (31/853508) two miles west of Westbury where the old iron workings are still well exposed. The ironstone occurs at the top of the Corallian and is overlain by Kimmeridge Clay. Members were able to collect from the bands full of *Ostrea delta* but did not find any *Ringsteadia*.

The party then moved to Trowbridge where on the north side of the town there is a large pit (31/858591) in Oxford Clay (recently abandoned as a brick-works). Despite the wet condition of the pit, members were able to collect some interesting crystals of Selenite and fragments of Kellaways Rock. The next area to be inspected was the historic locality for corals south of Steeple Ashton (31/909562). The coral reefs formerly exposed are now either a portion of arable or pasture land or part of a former war-time aerodrome. The Director was, however, able to show a large lump of the coral *Isastraea* found in one of the fields and to take the party into an old lime-working (31/906561) where an oolitic facies of Corallian yielded several fossils.

After lunch at the Bell Inn, Seend, two quarries were visited in the neighbourhood. The Lower Greensand outlier at Seend (31/937610) is highly ferruginous and has been quarried from time to time as an ironstone. About 100 feet lower down the hill-side is an old quarry (31/931609) in the Calcareous Grit of Corallian age. Some members were able to find the level at which ammonites can be obtained and extracted one or two good specimens. The last exposure (31/942649) to be visited was also in the Calcareous Grit, which forms 'The Sandridge' that runs from Melksham to Bromham. By permission of the manager of The Sahara Sand Company, some fresh sections and large slabs of grit were inspected. Some sections showed fine examples of current bedding and the large slabs contained a few fossils.

Mr. F. Stenhouse Ross proposed a vote of thanks to the Director and the party dispersed.

The Stratigraphy and Structure of the Middleton Tyas-Sleightholme Anticline, North Yorkshire

by ALAN J. WELLS

Received 5 July 1955; taken as read 5 April 1957

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ABSTRACT: The sequence of the Carboniferous rocks, Middle and Upper Limestone Group, exposed in the anticline between the middle Tees and the middle Swale is described. The lowest horizon exposed in the middle of the structure is correlated with the Simonstone Limestone of the Wensleydale succession. Detailed mapping shows the Three Yard Limestone to have been apparently cut out by erosion in the eastern part of the area. A littoral facies of the Underset Limestone is traced, and the stratigraphy of chert developments above the Underset and Main Limestones is described. A minor but widespread unconformity in the beds above the Main Limestone is deduced, and the very variable Richmond Chert Series (developed over the Little Limestone) is recognised.

The detailed structure of the east–west anticline on the north-eastern part of the stable Askrigg Block is presented. This anticline is seen to pass directly into the Cotherstone (Stainmore) syncline to the north-west. The pre-Permian age of the anticline is proved, and the probable structure in early Tertiary times is indicated. The joint system is analysed, and its formation by a roughly north-west/south-east compression (combined with simultaneous tension at right angles) is postulated.

1. INTRODUCTION

THE MIDDLETON TYAS–SLEIGHTHOLME ANTICLINE is an east–west structure lying across some 130 square miles of country between the towns of Barnard Castle in County Durham and Richmond in the North Riding of Yorkshire. It occupies ground which rises gradually from 200 feet O.D. in the east to over 1800 feet O.D. on hill-tops in the west. This easterly slope is general over the Northern Pennines as a whole, and may be regarded as a gently tilted plateau surface across which all the major rivers flow in an easterly direction. The area to be described lies between two of these major rivers, the Tees and the Swale, and thus lies entirely within the North Riding of Yorkshire.

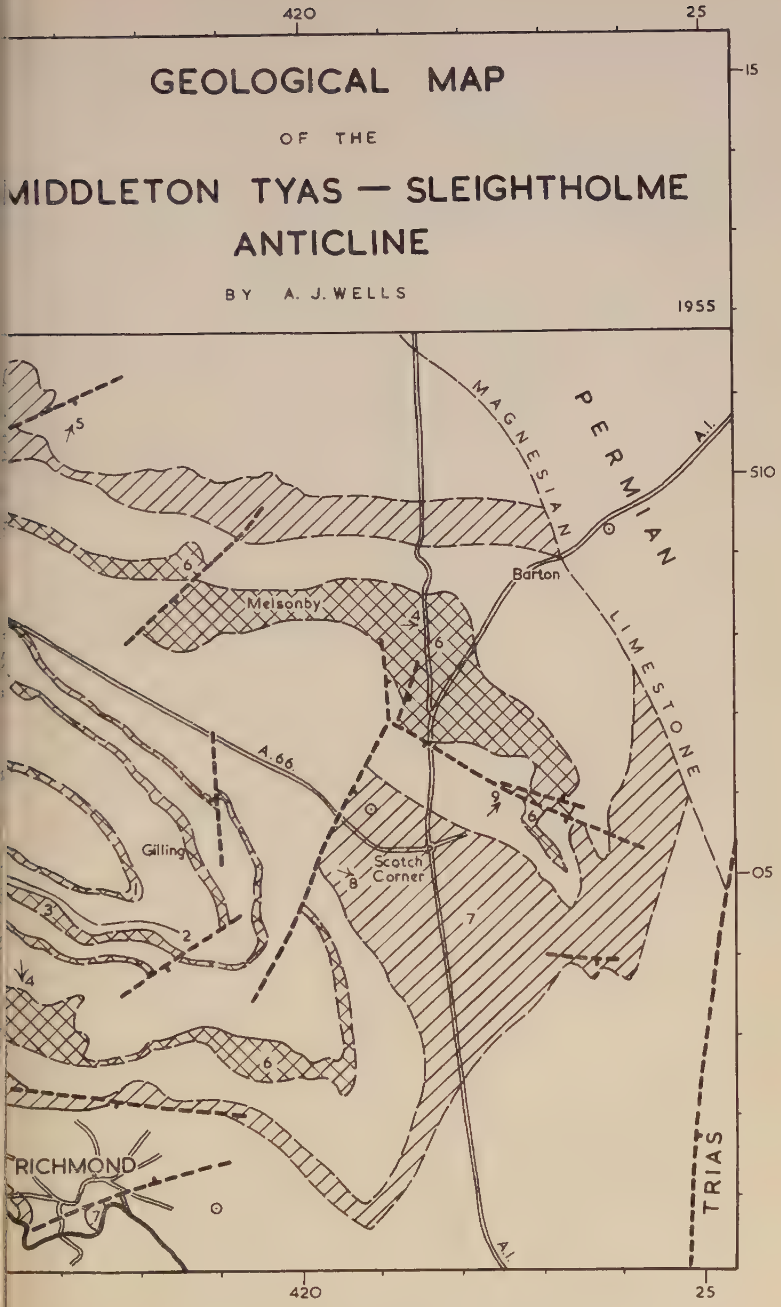
The Middleton Tyas–Sleightholme anticline is bounded by a closed outcrop of the Main Limestone, marking the base of the Upper Limestone Group of the Carboniferous Limestone Series. Within this outcrop is exposed the upper part of the Middle Limestone Group. The anticlinal structure is complicated by a number of subsidiary domes along its axis, by far the most important of which is the Gilling dome, and it is there that the Middle Limestone Group is best seen. The north flank of the anticline passes directly into the important Cotherstone (Stainmore) syncline, but the south flank is less well defined, and passes, through much-faulted ground, into a shallow synclinal area along Swaledale. Eastwards the structure plunges beneath the unconformable Permian Magnesian Limestone. Westwards it gradually fades out, further folds developing *en echelon* and to the south of it.

The beds up to and including the Main Limestone fall into the regular rhythmic pattern of the Yoredale Series, which consists essentially of repetitions of the sequence sandstone on shale on limestone. Of these, the limestone member is generally the most constant and best exposed, while the shale is not often seen. The sandstone member is usually a feature-forming horizon, and is easily followed where the drift cover is not too thick. But lateral facies variations are very rapid in these predominantly fresh-water beds, and the mapping of individual horizons is often difficult. Above the Main Limestone the simple Yoredale rhythm is considerably complicated by the development of thick cherty deposits and rapid lateral variations from and within this facies. The essential rhythmic character is still present, however, even if in a much modified form.

(a) Geological Succession

The geological succession established during the present survey is summarised in the following table. The generalised thicknesses are compiled from sections throughout the area.

		Thickness in feet
Permian	Magnesian Limestone	over 50
	Basal conglomerate and breccia	0 to 48
	unconformity	
Carboniferous	Millstone Grit: coarse grit, pebbly in part, with interbedded sandstones, shales and thin coals	over 100
	unconformity	



GEOLOGICAL MAP
OF THE
MIDDLETON TYAS — SLEIGHTHOLME
ANTICLINE
BY A. J. WELLS
1955

[*To face p.* 232

CARBONIFEROUS LIMESTONE SERIES

Upper Limestone Group	*Thickness in feet*
Crow Limestone and chert	8 to 60
Ten Fathom Grit	0 to 80
Shale	2 to over 50
Richmond Chert Series	12 to 130
Little Limestone	0 to 8
Coal Sills Group	0 to 150
Main Chert	0 to 30
Shale	0 to 18
Main Limestone	30 to 85
Middle Limestone Group	
Sandstone and shale	45 to 120
Underset Chert	0 to 26
Shale	0 to 20
Underset Limestone	12 to 65
Sandstone and shale	105 to 165
Three Yard Limestone	0 to 15
Sandstone and shale	30 to 120
Five Yard Limestone	24 to 30
Sandstone and shale	100 to over 145
Middle Limestone	48
Sandstone and shale	70
Gillingwood Limestone	7
Sandstone and shale	120
Simonstone Limestone, base not seen	at least 15

(b) History of Research

The geology of the region covered by the present survey has been sadly neglected since the time of its original mapping by officers of the Geological Survey prior to 1890. The first published information on the geology of this part of the Pennines is to be found in Volume 2 of John Phillips's *Illustrations of the Geology of Yorkshire* (1836), a masterly account which touched on many aspects of the subject. Westgarth Forster first published a succession for the Pennines north of Stainmore in 1809, and Phillips was quick to appreciate the fact that a similar succession could be made out to the south of Stainmore, and in particular recognised the continuity of the limestones. Phillips's name of Yoredale Series for these beds was adopted by the Geological Survey when the primary mapping was done, but unfortunately no accompanying memoir was published with Sheet 41 (New Series), within which falls most of the ground covered by the present survey. The extreme south-western corner of the mapped area was described, however, in the Mallerstang memoir (Dakyns *et al.*, 1891), which was issued in explanation of the adjoining Sheet 40.

Although the rhythmic succession in Wensleydale had been described by Phillips in 1836, it was left to Miller in 1887 to realise the significance of the rhythmic character of this type of sedimentation in his description of the Lower and Middle Limestone Series of the Otterburn district of Northumberland. Subsequently Hudson (1924), in a description of the rhythmic series in Wensleydale which was the first really detailed account to be published on Yoredale sedimentation, amplified Miller's views. Also in 1924 Kendall & Wroot completed their book on *The Geology of Yorkshire*, in which are to be found (as well as many interesting anecdotes) a number of original observations relating to the geology of the Middleton Tyas anticline (as it was known by the authors), and in particular to the understanding of some of the important glacial features. These latter were described by Raistrick (1926) in an account of the glaciation of the region, which has been amplified by a report on the glacial work carried out during the present investigation (Wells, 1955). After Raistrick's paper, no work relating directly to this area was published until Carruthers included a section from Sleightholme Beck (south-west of Bowes) in his stratigraphical adventure of 1938. There followed another long lull which was only broken in 1957 by Rowell's work on the Upper Limestone Group to the west of Arkengarthdale Head, and in 1957 by Reading's account of the stratigraphy and structure of the Cotherstone syncline. The ground covered during the present survey overlaps for a short distance (in the vicinity of Bowes) with that mapped by Reading, thus ensuring continuity across this important section.

The view that the Northern Pennines acted during Lower Carboniferous times as a rigid block was first put forward by Marr (1921). This block was recognised as being divided into two complementary halves by the Cotherstone syncline (which had been detected by Phillips eighty-five years previously). The northern half was named the Alston Block (Trotter & Hollingworth, 1928), the stratigraphy and structure of which has been admirably summarised by Dunham (1948), while the southern part was termed the Askrigg Block (Hudson, 1938). The present survey covers the north-eastern corner of the Askrigg Block, and Reading's recent work is particularly useful in linking the stratigraphy of the two blocks.

The first mention of the Middleton Tyas anticline as such is by Kendall (1911, p. 54), who considered it to be continuous with the Stowgill anticline described by the authors of the Mallerstang memoir in 1891, and to run eastwards across the Cleveland country to the sea at Robin Hood's Bay. The anticline was first recognised in print (although not named) the previous year by Marr (1910, p. 650), who referred to a major east–west anticline, pitching east, and bringing up a narrow strip of Lower Carboniferous beds between Richmond and Barnard Castle. He also saw that the structure was pre-Permian. The primary surveyors had presumably also recognised the importance of the anticline, but because of the lack of any descriptive work to accompany their map, we have no positive proof of this. Versey (1927) disagreed with Kendall's view that the Middleton Tyas and Stowgill (Howgill) anticlines were continuous, and it has subsequently been shown that there are a series of three separate *en echelon* folds. The two westerly ones have been described by Rowell & Scanlon (1957), and the most easterly one is the subject of the present research.

2. THE SIMONSTONE CYCLOTHEM

The basal limestone member of this cyclothem, originally named the Simonside by Phillips (1836) in his description of the Yoredale Series in Upper Wensleydale, has been known as the Simonstone since the original mapping of 1 in. Sheet 40 by the Geological Survey, which covered Phillips's type area. When the primary survey of the area covered by the present work was made, some eighty years ago, the limestones which were mapped as closing round the Gilling dome were named the 3rd, 4th and 5th Set Limestones, no correlation of the beds beneath the Underset Limestone being implied. It can now be shown (see p. 239) that the Three Yard Limestone, as mapped by the Geological Survey in upper Swaledale, is not seen in the succession round the Gilling dome, and that the 5th Set Limestone can be correlated with the sixth limestone beneath the Main, i.e. the Simonstone.

The succession in this cyclothem is shown in section (a) of Fig. 2.

The Simonstone Limestone is the lowest horizon mapped in the present survey, and members of the cyclothem are exposed at intervals on the south side of the Gilling Valley between Gilling Wood and the Gilling–Richmond road, a distance of about one and a half miles round the south side of the dome, where the radial dip away from the centre is very striking. The limestone here is about fifteen feet thick, and is crinoidal, with many foraminifera, and is noticeably bituminous.

Above the limestone there is an unexposed gap of some seventy feet, presumed to represent shale. This is followed by fifty feet of current-bedded sandstone, the top of which passes up into a thin limestone (here called the Gillingwood Limestone), to be correlated with that of the minor rhythmic unit of Hudson (1924, p. 127) in the Simonstone cyclothem of Wensleydale, and also with the thin limestone of Dakyns *et al.* (1891, p. 110), occurring in part of upper Swaledale about fifty-five feet below the Middle Limestone. Worthy of mention are the crinoid ossicles up to three-quarters of an inch in diameter in the sandy passage beds leading up to the Gillingwood Limestone.

The rest of this composite cyclothem is very poorly exposed, and presumed to be mainly shale, but there are several places where a thin sandstone is visible beneath the Middle Limestone.

3. THE MIDDLE CYCLOTHEM

The beds assigned to the Middle cyclothem which outcrop in the core of the anticline occur in two separate areas, each bounded by a closed outcrop of the Five Yard Limestone. The larger of these is to be found round the Gilling dome. The authors of the Mallerstang memoir (1891, p. 106), in describing the Middle Limestone of Swaledale, state that it usually occurs in three parts, and in places makes three separate features, and they have no hesitation in comparing it with the Single Post, Cockle Shell and Scar Limestones of the Alston Block. Round the Gilling dome, the Middle Limestone occurs in two parts, which, in places on the south side of the valley, make separate well-defined features. But the giganteid producti typical of the Cockle Shell Limestone north of Stainmore occur both above and below the shale band dividing the Middle Limestone, and it is not possible, in this instance, to suggest correlations directly with the Alston equivalents.

Around Brignall Banks, an inlier of beds of the upper part of the Middle cyclothem occurs in the River Greta.

Comparative sections for the cyclothem are shown in Fig. 2.

The Middle Limestone round the Gilling dome is exposed on both sides of the valley. On the south side, it makes one, and sometimes two, excellent features, which can be traced from the Gilling–Richmond road to Whashton. The best exposure is in Long Acres quarry (45/181042)[1], near the road, where the full thickness of forty-eight feet is seen. It is of the normal dark grey crinoidal type, but there is a shale band near the middle, which effectively divides the limestone into two. Very striking are the large productids (the largest seen being thirteen inches across) and a horizon of chert nodules which have been formed by replacement.

The overlying shale, estimated to be forty feet thick, is exposed in two places only, where its base is seen resting on the Middle Limestone, and its top is marked in several localities by springs issuing from the base of the overlying sandstone. The sandstone, some sixty feet thick round the Gilling dome, is largely massive and current-bedded. Dakyns *et al.* (1891, p. 107), when describing this horizon in Swaledale, had no hesitation in connecting it with the 'Lower Brigstone Hazle' of Alston Moor, the Low Brig Hazle of Dunham (1948, p. 19), but lateral facies variations are so rapid that correlation of individual sandstones over such a distance could be dangerous. In the Brignall Banks inlier, over 140 feet of often massive and current-bedded sandstone, alternating with shale bands towards the base, are almost continuously exposed. The cyclothem is here considerably thicker than in the Gilling region, where there are only 100 feet of beds above the limestone, and there is no sign in the Greta that the Middle Limestone is even nearly approached, to judge by the high proportion of clastic material in the lowest exposed horizons. Part of the thickening has evidently taken place in the sandstone at the expense of the underlying shale.

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[1] Six-figure numbers are National Grid references.

4. THE FIVE YARD AND THREE YARD CYCLOTHEMS

The Five Yard and Three Yard cyclothems are dealt with in a single section because over the eastern half of the mapped area the Three Yard Limestone is not seen, and is thought to have been cut out, so there is no consistent marine horizon with which to separate the beds between the Five Yard and Underset limestones.

The Five Yard Limestone is the Impure Productal Limestone of Phillips (1836), but he did not recognise the thinner limestone between it and the Underset Limestone. The names now applied to these two horizons originated as miners' terms, and were adopted during the Primary Survey of 1 in. Sheet 40. The Five Yard Limestone had been called both the Third Set and Fourth Set by some Swaledale miners, depending on whether or not the Three Yard Limestone was recognised, which led to some confusion. During the Primary Survey of the area, the Three Yard Limestone was seen in two places, but not recognised as such, and the limestones closing round the anticline were numbered in 'Sets', counting down from the Main Limestone. Thus the Five Yard Limestone was everywhere called the Third Set, while the Three Yard went unnamed. One of the clues to the identity of the horizons inside the outcrop of the Underset Limestone lies on the south side of Swaledale, in the section up Greenseat Beck (35/899972), which meets the Swale between Thwaite and Muker. The limestone at about 1200 feet O.D., the Middle Limestone of the Survey, contains common giganteid producti and some corals, and lithologically is very similar to that in Long Acres quarry, called the Fourth Set by the Survey. Also, the Three Yard Limestone, as mapped by the Survey, is here seen to be in two parts, the upper one containing 'tubes' running down from its upper surface, and the lower one resting on fossiliferous sandstone. It is so similar in detail to two small and unusual limestones seen and mapped near Barningham, which occur between the Underset and 'Third Set' limestones, that there is no hesitation in assigning the Barningham limestones to the Three Yard horizon, which will make the Third Set of the Survey correspond to the Five Yard, and the Fourth Set correspond to the Middle, a correlation already suspected by the presence of abundant giganteid producti. From this, it follows that the Fifth Set will correspond to the Simonstone, as was noted on p. 235 above. Examination of the Three Yard Limestone of the Survey in Gunnerside Gill (35/939005, on the north side of Swaledale) and in Punchard Gill (35/969047, near the head of Arkengarthdale), lent further support for the above correlation.

Among the most abundant and most easily recognisable fossils in the

Middle Limestone Group, due to their commonly complete preservation, are the foraminifera, and one of the most characteristic of these is *Howchinia bradyana* (Howchin), which in vertical section looks like an old-fashioned beehive. Its distribution in the Lower Carboniferous of Northern England was described by Davis (1951), who concluded that it is known only between D_{I} limestones and high in P_2. The youngest specimen recorded by him from a definite horizon was from a quarry in the 'Third Set Limestone' near Gilling. *Howchinia* has now been recognised in every limestone closing round the Gilling dome, and also in the Underset Limestone, being present in most of the slides examined, often in considerable numbers. Its range can therefore be extended to cover both the Five Yard and Three Yard cyclothems.

Comparative sections for the Five Yard and Three Yard cyclothems are shown in Fig. 3.

The Five Yard Limestone round the Gilling dome is normally a dark grey crinoidal limestone, with brachiopods usually in fragments, but sometimes occurring complete. It makes a broken feature along the north side of the Gilling Valley between Warrener Lane and Gilling Bank, but on the south side it is easily traceable between Aske Park and Whashton Springs. The dip, always away from the centre of the dome, varies between five and sixteen degrees. At Whashton Springs (45/152047), thirty feet of the limestone are exposed in a quarry which must show very nearly the full thickness. It is here comparatively rich in productids and their spines. The Five Yard Limestone is better seen, however, in and around Brignall Banks, where it makes another closed outcrop. Its full thickness is seen to vary between twenty-four and thirty feet. Dakyns *et al.* (1891, p. 107) give twenty feet as an average thickness for upper Swaledale, but state that it may sometimes attain thirty feet. Northwards on the Alston Block, however, the average thickness of the sections quoted by Dunham (1948, p. 21) is definitely less than twenty feet, while in Wensleydale, to the south, it is only ten feet (Dakyns *et al.*, 1891, p. 95), so the Five Yard Limestone can be considered, in the area of the present survey, to be at about its maximum development. When seen in thin section, scattered small ooliths are nearly always present, and these, combined with the fragmentary brachiopod and bryozoan remains, would imply deposition in very shallow water, a conclusion which holds equally for the three underlying limestones. A noteworthy feature of this horizon is the occasional occurrence of quartz-filled cavities, of very variable size, which suggests that a certain amount of silica is normally present in the limestone and has locally been concentrated (but see 6, below).

The Three Yard Limestone is seen only in four widely separated localities, and no attempt has been made to join up these scattered outcrops on the map. In the two best exposures, at Scotchman's Stone, near the eastern end of Brignall Banks (45/081125), and in an unnamed beck half a mile south-west of Barningham (45/078099), the limestone is in two parts, separated by a thin non-marine horizon. The former shows the total thickness to be twelve feet four inches, the latter about fifteen feet, and in both cases there is a gradual passage up into the lower limestone from the underlying sandstone. A decalcified sample of the upper limestone at Barningham yielded much glauconite, also pyrite, fluorite and a little sphalerite, together with a small conodont fragment. A bore-hole at Mount Pleasant, one and a half miles south-west of Barnard Castle (45/033151), penetrated the Three Yard Limestone, where it is twelve feet six inches thick and also divided by a non-marine horizon. These occurrences can be compared with those in upper Swaledale, described by the authors of the Mallerstang memoir (p. 108), where the thickness is stated to be generally about ten feet. In Waitgate Gill (45/083047), on the north side of the Faggergill–Waitgate Fault, five feet of the Three Yard Limestone are overlain unconformably by a massive sandstone which has cut out the rest of this horizon. As there is no further sign of the Three Yard anywhere east of Waitgate Gill, this is taken as evidence for its complete absence in that area due to transgression by the overlying sandstone.

The beds between the Five Yard and Three Yard limestones are best seen in Brignall Banks, where the limestones are separated by ninety-one feet six inches of shales and sandstones, including a marine sandstone with giganteid producti twenty-six feet down from the upper limestone. The sandstone underlying the Three Yard Limestone is only fourteen feet thick in Brignall Banks. This is less than half the average for the High Brig Hazle of Teesdale, which occurs at the same horizon (Dunham, 1948, p. 20). On the other hand, the Five Yard cyclothem here is over half as thick again as the average value over the Alston Block.

Above the Three Yard Limestone, a thick shale is visible in Brignall Banks, and is overlain with slight unconformity by at least fifty feet of massive non-marine sandstone, the base of which varies between sixty-six feet and forty feet above the top of the limestone. At least part of this transgressive sandstone is in the form of a wash-out, running roughly north-west/south-east. The sandstone equivalent in horizon to the Natrass Gill Hazle of Teesdale and farther north is about twenty-five feet thick along the north side of Swaledale, but it is inconsistent, and reaches as much as ninety feet on Aske Moor. A horizon that has proved to be remarkably constant, however, is a band of virtually unconsolidated sand, found usually between two and four feet below the base of the Underset Limestone.

Around the Gilling dome, where the Three Yard Limestone is nowhere seen and thought to be absent, it has been possible to map parts of several sandstone bands in certain places between the Five Yard and Underset

Limestones. Of these, the one underlying the Underset is best seen, particularly south-west of Gilling. It is called the 'Twenty-seven Fathom Grit and Plate' on the maps of the Primary Survey, but it certainly never attains a thickness of twenty-seven fathoms in this area. It does become fairly coarse towards the top, and is extremely false-bedded in part. It is composed of quartz grains with strong strain shadows (biaxial, with 2V about 5°), which are accompanied by plagioclase, zircon and, in one instance, sphene, this material almost certainly being derived from regionally metamorphosed acid igneous rocks.

5. THE UNDERSET CYCLOTHEM

The Underset cyclothem is one of the best known of the rhythmic units comprising the Middle Limestone Group to the south of Stainmore, and the Underset Limestone, which marks its base, is easily recognisable in most places by its proximity to the thick overlying Main Limestone. Over the Alston Block (where the limestone at the base is known as the Four Fathom Limestone) this interval has been penetrated by many mine workings, and in nearly every case is seen to be a double cyclothem, a thin limestone known as the Iron Post, complete with underlying sandstone (the Quarry Hazle), occurring between the Four Fathom and Great Limestones (Dunham, 1948, p. 23). When Reading (1957) re-mapped the Cotherstone syncline, he found that the Iron Post horizon was also recognisable over most of that area. But he could find no trace of either it or the underlying Quarry Hazle in the Bowes region, where outcrops are separated from their nearest equivalents to the west by eight miles, and to the north by six miles. So somewhere within this interval the Iron Post Limestone as such has died out, and it is significant that no evidence for its existence has been discovered anywhere during the present survey of the ground to the south-east of Stainmore. Reading considered that in the region of Bowes there was continuous marine deposition contemporaneous with the formation of a normal cyclothem to the north and west. But to the south and east, the thickness of marine beds above the Underset is no greater than usual, and the interval between the bases of the Underset and Main Limestones is a single normal rhythmic unit, apart from the development of chert in places. Southwards, in Swaledale and Wensleydale, the Survey found no evidence of the Iron Post either, although it was apparently picked up in places on Winton and Kaber Fells, some ten miles west-south-west of Bowes (Dakyns *et al.*, 1891, p. 133).

Dr. G. A. L. Johnson made a most important find when he collected several goniatites, including *Girtyoceras*? *costatum* Ruprecht, from the lower part of the shale separating the Underset Limestone and Chert, in the core of the Mount Pleasant bore. These indicate a high P_2 horizon, and as the base of the Main Limestone is generally agreed to lie within the *Eumorphoceras* Zone, the boundary between the Lower and Upper Carboniferous would thus appear to lie between the Underset and Main Limestones. The present position is admirably summarised by Rayner (1953, pp. 285–90). Comparative sections of the Underset cyclothem are shown in Fig. 4.

The Underset Limestone has been mapped as a closed outcrop all the way round the anticline. For the most part, it is a compact crinoidal limestone, but somewhat lighter in colour than the other Yoredale limestones seen in this area, normally being a creamy-grey colour. It varies greatly in thickness, being only twelve feet in its most westerly exposure at Gilmonby Bridge (35/995133), below Bowes, but the more normal thickness of twenty-five feet in the bore-hole at Mount Pleasant two and a half miles away to the north-east. East of a line running roughly north/south through Richmond, however, the upper part of the Underset has a very different lithology, being composed almost entirely of coarse crinoidal debris, strikingly current-bedded, which was deposited rapidly by strong currents which came from a northerly direction. In this area, at the eastern end of the structure, the Underset Limestone is at least sixty-five feet thick, which is the highest recorded figure north of Wensleydale, though the authors of the Ingleborough Memoir (Dakyns *et al.*, 1890) measured greater thicknesses than this in several places farther south. Miller & Turner (1931) described a bed of rolled corals from near the base of the Underset Limestone along the Dent Fault, which has since been recognised in much of upper Swaledale (Turner, 1956), and Reading (1957) has recorded it everywhere round the Cotherstone syncline except in the Bowes region. This coral bed was not seen anywhere during the present survey, it being apparently absent to the east of Arkengarthdale.

In places north of Stainmore, and also in upper Swaledale, the Underset Limestone is sometimes characterised by *Saccamminopsis fusuliniformis* McCoy, and often by chert nodules. The former has been recorded from only one locality during this work, but the latter occur commonly throughout the limestone, sometimes in well-defined bands. The base of the Underset Limestone normally has a sharp junction with the underlying beds, but in several cases there is a gradual transition upwards from sandstone. The bottom few feet, over much of the area, have been recrystallised and dolomitised, now being a characteristic buff colour, and over about eight square miles to the north of Marske, the lowest few inches of the limestone have been silicified to a thin black chert band.

In many places south of Stainmore, a cherty series is developed on, or a little above, the Underset Limestone. There is no record of it on the Alston Block, and Reading (1954) found it to be absent across most of the Cotherstone syncline, only making its appearance on the south side, in the Bowes region, where outcrops are limited to the vicinity of the village. It there consists of up to sixteen feet of hard fossiliferous mudstone and dark chert bands, separated from the Underset Limestone by twenty feet of shale which Reading considered to be the lateral equivalent, in part, of the Iron Post Limestone. Along the south side of the anticline, however, outcrops of chert occur, separated from those near Bowes by at least seven miles, which lie directly on the Underset Limestone. This is the normal occurrence throughout much of Swaledale and Wensleydale, and it is most probable that the chert series at Bowes is at a different horizon to that found farther south and south-east. The occurrence of chert is very sporadic, however, and in upper Swaledale and Arkengarthdale its thickness varies rapidly between zero and thirty-six feet, the maximum occurring near Reeth (Dakyns *et al.*, 1891, pp. 110 and 116). The greatest thickness of chert encountered during the present survey was twenty-six feet, north of Marske. Through a combination of surface outcrops and sub-surface information, it is known to thin towards, and be absent north and east of a line drawn roughly from Barnard Castle to Barningham Moor, along the south side of the Gilling Valley and across to Middleton Tyas. On the south side of the Swaledale–Gilling Valley watershed it becomes well developed, and generally takes the form of a banded series of siliceous mudstones and dark cherts, which commonly contain calcareous sponge spicules. There is no evidence of organic origin for the silica, which is considered to have been chemically precipitated at the time of deposition.

The shale between the Underset Limestone and Chert, from which the goniatites were obtained in the Mount Pleasant bore, is exposed in one place only, at Gilmonby Bridge, near Bowes. Diligent searching here by a number of people has failed to find any goniatites, but *Posidonia membranacea* (McCoy), which occurs with the goniatites at Mount Pleasant, has been obtained. In the beds overlying the Underset Chert in the Bowes area, clastic material accounts for only a very small proportion of the cyclothem, and in places is virtually absent. Around Bowes, and westwards at least as far as God's Bridge (35/956127), a thin coal underlies the Main Limestone, beneath which a very thin and variable sandstone rests on shale, which continues down to the Underset Chert. Thus the Tuft Sandstone of Stainmore and farther north is hardly represented. But farther south-east, along the south side of the Gilling Valley, a very strong sandstone develops beneath the Main Limestone, although on the north flank of the anticline it remains thin and broken up by shale bands. An interesting exposure occurs in East Layton quarry (45/155106), where it contains a comprehensive suite of copper-bearing minerals, including bornite and chalcanthite. High on Barningham Moor, near the watershed between the Greta and the Swale, the sandstone is at least sixty feet thick, which is considerably greater than any record for the complete Iron Post cyclothem north of

Stainmore (Dunham, 1948, p. 25). It is unusual to find coal capping this sandstone, which often becomes coarse near its top, and although a gradual passage up into the overlying Main Limestone has been recorded from several localities, a sharp junction is much more common. In the Richmond area, this sandstone contains about twenty per cent feldspars, and is properly described as arkosic.

The separation of the Underset and Main Limestones averages 100 feet over the area, although in the west, where the equivalent of the Tuft is almost unrepresented, it falls to about eighty feet, and in the extreme east, around Middleton Tyas, it is apparently as little as fifty feet. This compares with between forty and seventy feet for upper Swaledale, and up to 150 feet in parts of Wensleydale (Dakyns *et al.*, 1891, pp. 92 and 110). On the Alston Block, the comparable interval is less variable, being generally about 100 feet, despite the composite nature of the cyclothem.

6. THE MAIN AND LITTLE CYCLOTHEMS

The Main and Little cyclothems are dealt with together in one section because over long stretches of ground in the south and south-east part of the area the Little Limestone, although presumably present, is unrecognisable as such, and the two cyclothems cannot therefore be everywhere differentiated.

Of particular interest are the variations in the beds above the relatively very constant Main Limestone, and the development of chert within them. Phillips (1836, p. 66) clearly correlated the Little Limestone with the 'Red Beds', a series of crinoidal reef limestones above the Main, which are well developed in lower Swaledale. When the Geological Survey covered the area, they used the 'Red Beds' as a mapping horizon, and were under the impression (Dakyns *et al.*, 1891, p. 10) that the 'Red Beds', together with the cherty 'Black Beds', passed laterally into the Coal Sills, a series of sandstones and shales well developed to the north and north-west. Hudson, in 1924 and again in 1941 (p. 266), also considered the 'Red Beds' and 'Black Beds' to be lateral equivalents of the Coal Sills, and to underlie the Little Limestone. Carruthers (1938, p. 252), on the other hand, stated that 'there can be no doubt at all that the Ten Fathom Grit is the Upper Coal Sill (possibly the Lower one also)', and that in Swaledale the Little Limestone comes below the Coal Sills. The Ten Fathom Grit of Swaledale is overlain by the Crow Limestone, which he considered to be the equivalent of the Little Limestone of the Alston Block, although the Primary Survey had mapped the limestone on the Coal Sills as the Little. And more recently Dunham (1950, p. 55) correlated the pale coarsely crinoidal limestones around Richmond with the Main, and thought that the muddy and siliceous marine beds in the same area passed northwards into the Coal Sills.

Turner (1935) and later Reading (1957) have confirmed the view of the Primary Survey that the Coal Sills and the overlying Little Limestone can be followed round the Cotherstone syncline, and straightforward mapping during the present work has confirmed that the Coal Sills underlie and are entirely separate from the Ten Fathom Grit, this having always been the generally accepted view. The feather edge of the Coal Sills delta is clearly defined between Teesdale and Swaledale, and to the east and south-east of this margin the Main Chert immediately underlies the Little Limestone. It has already been shown from a consideration of eighty-three measured sections in Swaledale and Wensleydale (Wells, 1955a, pp. 178–80 and Plate 16) that an unconformity exists beneath the Little Limestone, the latter progressively transgressing southwards over the lower beds until near Leyburn it is resting on the Main Limestone.

In lower Swaledale, lenticular bodies of coarse crinoidal reef limestone are developed in the Richmond Chert Series overlying the Little Limestone, and it is these to which the term 'Red Beds' has been applied. The 'Black Beds' were the more argillaceous horizons in the same series in this region, while farther west and north-west the term was applied to the Main Chert, beneath the Little Limestone. So it is small wonder that the authors of the Mallerstang memoir (Dakyns *et al.*, 1891) were sometimes uncertain (p. 110) about the relative ages of their 'Red Beds' and 'Black Beds'. And the original correlation made by Phillips when he equated the 'Red Beds' with the Little Limestone is thus closer to the results of the present survey than any of the succeeding views, and in fact differs from it mainly by a detail of nomenclature. Comparative sections for the Main and Little cyclothems are shown in Figs. 5A, 5B and 5C.

The Main Limestone (known as the Great north of Stainmore) is by far the thickest and most constant of the Yoredale limestones mapped during this survey. It is well bedded, often in posts up to four or five feet thick, and is normally a characteristic pale grey colour. It is crinoidal, but relatively poor in other macrofossils, although thin sections generally reveal an abundance of shell debris among which formaminifera are common. The thickness varies between thirty and eighty-five feet, with sixty feet as a normal figure, the latter also being a fair average for the Alston Block (Dunham, 1948). Variation is rapid, however, the maximum and minimum thicknesses occurring on the north flank of the anticline within two and a half miles of one another. It is usual for the bottom few feet to be brown and dolomitised, as is also the case with the Underset Limestone, and it is suggested that this was caused by percolation of magnesium-rich ground waters, probably during the time when the area was overlain by the Permian Magnesian Limestone (see section 7). The main bulk of the limestone has a striking silica content, shown by analyses to be as high as ten per cent. Chert nodules occur, but are less common than in the Underset Limestone, and silica is very rarely seen in thin sections, although occasional quartz crystals up to two centimetres in length have been recorded. The rich coral-brachiopod band of Weardale, known as the Frosterley Marble, was shown by Reading (1957) to die out across Stainmore, but in places thin and impersistent coral bands, mainly of *Dibunophyllum*, are seen at several levels, and a bed of *Chaetetes depressus* (Fleming) and *Lonsdaleia* cf. *laticlavia* S. Smith occurs just above the base near Richmond.

In the Bowes region, the Main Limestone is overlain by alternating shales and calcareous mudstones (correlated by Reading with the Tumbler Beds of the Alston Block), above which comes the Main Chert, here a series of banded well-bedded flinty cherts of very local occurrence, but up to twenty-six feet thick in Chert Gill (35/987118). The Main Chert dies out to the north-east and south-west with extraordinary rapidity, apparently passing laterally from its maximum development, in no more than a mile, into black shale which overlies the so-called Tumbler Beds beyond the limits of the chert. But south-east from the Bowes region the Main Chert persists, although it changes in facies from a banded chert to a series of siliceous mudstones, calcareous shales and impure limestones.

Above the Main Chert over the western part of the mapped area are the Coal Sills. These are a variable series of sandstones and shales, well known on the Alston Block, and which there commonly carry coal seams (locally workable) above the sandstone members, normally three in number. South of Stainmore, however, only two sandstones are developed, which are here called the Upper and Lower Coal Sills without implying exact correlation

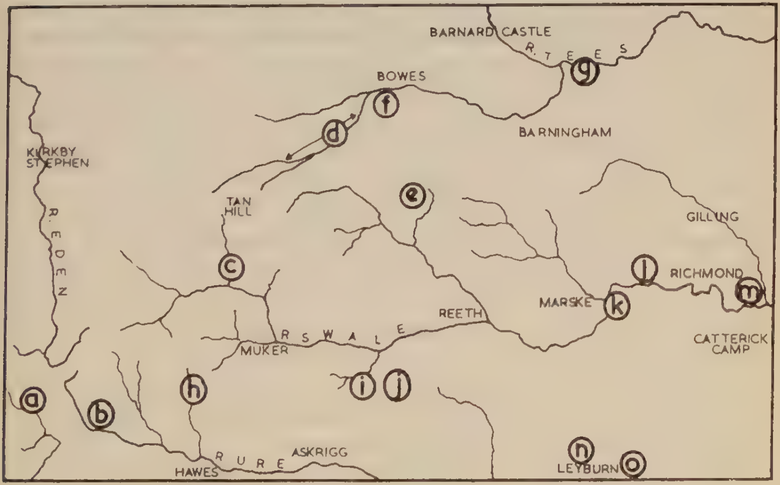

Fig. 5A. Localities of sections shown in Figs. 5B and 5C

with those farther north. But Reading found the Upper Coal Sill in the Bowes area to be a continuous mappable horizon which he equated with the White Hazle of Dunham (1948, p. 27). The two Coal Sills are here separated by shale in which a thin unnamed marine limestone occurs, this passing westwards into fossiliferous sandstone. In the northern part of the Stainmore area, Reading recorded three impersistent marine bands within the Coal Sills, and used the supposed equivalance of the marine 'Red Beds' and 'Black Beds' of Swaledale with the Coal Sills (a correlation now shown to be incorrect) as evidence of the proximity of the sea during that time. No coal is seen *in situ* in connection with the Coal Sills south of Stainmore, but loose fragments in the banks of Sleightholme Beck suggest a seam at or near the top of the lower sandstone. Traced south-east from the Bowes region, the Lower Coal Sill soon dies out. The upper one persists for about a mile farther, characterised by abundant worm tracks (the 'wormy grits' of the Mallerstang memoir), until it also disappears, leaving the Little Limestone, which normally overlies the Upper Coal Sill, resting either on the Main Chert or on black shale, depending on whether or not the former is developed.

The Little Limestone (or Upper Little, to distinguish it from a limestone of the same name low in the Middle Limestone Group) is a grey crinoidal bed, often containing small sand grains visible in thin section, and has been seen up to seven feet in thickness. It is characterised by more or less vertical tubes, up to eighteen inches long, partly chert-filled and running down into the limestone from a thin cherty bed at the top, and which are often very well seen on weathered surfaces. These tubes, together with the cherty top (commonly slightly glauconitic), are developed over a very wide area in North Yorkshire and parts of Westmorland, and were first described by Rowell & Scanlon (1957) from Kaber Fell, and subsequently found, quite independently, through much of Swaledale, Wensleydale and adjoining areas during the present survey, where they were used as an aid to identification of the Little Limestone. It was Rowell's view that these tubes were infilled polychaete borings. If this is the explanation, as seems likely, the top of the Little Limestone will mark a short depositional break.

The Little Limestone is overlain by a very variable series of fossiliferous siliceous limestones and mudstones which, although not for the most part strictly cherts, are sufficiently siliceous to be called a chert series, and have been named after the town of Richmond, in the vicinity of which they reach their maximum development of about 130 feet (Wells, op. cit., pp. 180–3). In the west the series is no more than twenty feet thick in places, the overlying shale being equivalent to the higher siliceous beds farther east. Rowell (1957) kept these cherts separate from the underlying Little, but Reading (1957) preferred to regard the Little as a marine series, which varied in thickness across Stainmore between twenty and thirty feet, the upper boundary of which was often indistinct. The term Little Limestone here refers only to the thin relatively pure and constant limestone band at the base, as it is clearly unsuitable for use with a series whose top is so strongly diachronic as that of the proposed Richmond Chert Series. In lower Swaledale lenticular crinoidal limestones enter into this series, and are so strongly developed around Richmond that the proportion of silica within the series is substantially reduced. These limestones sometimes weather a pale yellow-orange colour, which led to the adoption of the term 'Red Beds' by the old miners. But due to lenticularity and minor erosion surfaces within these beds, detailed sections through the series show wide variations over quite short distances. Despite this, one band of white chert, about four feet thick, which is developed towards the top of the series, is remarkably constant, and has been used as a mapping horizon, being an invaluable marker for position within this variable series. It outcrops just beneath the top of the valley sides in lower Swaledale, and has been named the Marske Chert Band, after the village around which it is so well seen. It has been traced as far west as Little Punchard Gill (35/957033), on the west side of Arkengarthdale, and is known to exist over an area of more than thirty square miles on the north side of Swaledale.

The Richmond Chert Series is succeeded by shale, substantially thicker in the west than in the east, which is overlain by the Ten Fathom Grit. In upper Swaledale the 'Grit' is commonly in two parts which are separated by a thin limestone (named the Faraday House Limestone by Rowell, and followed by Reading into Stainmore) and sometimes by a coal. It is particularly well developed west of Reeth and in Arkengarthdale, where it often exceeds sixty feet in thickness (Dakyns *et al.*, p. 111), and is overlain by the Crow Limestone. It has been mapped between the head of Arkengarthdale and the moors west of Marske, and although of considerable thickness, it is never coarse enough to be comparable with true Millstone Grit facies. The Faraday House Limestone, if developed, is nowhere exposed within this area. East of Marske, however, sections on the south side of Swaledale show very rapid thinning of the Ten Fathom Grit, and half-way to Richmond it is represented merely by a few thin sandstone bands in shale, while a mile south-east of Richmond it has gone altogether, the Richmond Chert Series being separated from the Crow Limestone by a few feet of shale.

7. STRUCTURE

The area under consideration lies immediately to the south-east of the Cotherstone syncline, in the north-east part of the stable Askrigg Block. The structure is summarised in Fig. 6, contours being drawn on the base of the Main Limestone at intervals of fifty feet, so that the map is directly comparable with those of Dunham (1948) for the Alston Block and Reading

(1957) for the intervening Cotherstone syncline. It is considered that the structure contours are accurate to within 100 feet over the whole of the map, but over much of it, especially in the vicinity of the outcrop of the Main Limestone, the margin of error will be less than fifty feet.

(a) Folds

The structure is essentially that of a gently easterly pitching somewhat asymmetrical anticline. The north flank of the anticline is simple, and passes without interruption into the southern limb of the Cotherstone syncline. The dip of this flank is of the order of four degrees or 350 feet per mile, which is rather less than the average in the syncline itself, the dip decreasing slightly on to the block. The axis of the anticline pitches in a direction ten degrees south of east at about 100 feet per mile, or slightly more than one degree, and its regularity is interrupted by three subsidiary domes. The easternmost of these, the Gilling dome, is a strong structure, second only to the anticline itself, and the main fold closes rapidly round the north, east and south sides of it, with dips locally in excess of ten degrees. The closure to the west of the Gilling dome is about 100 feet, and it passes, by way of the Feldom Fault, into the Whashton dome, a small but comparatively sharp flexure. This is slightly elongated along an east–west axis, and dips off it to the north and south are as high as twenty degrees. The closure round the Whashton dome is a minimum of 125 feet, and it passes westwards along the axis into an elongated open area between Byers Hill (45/070075) and Stang (45/015072), along the Teesdale–Swaledale watershed. West of Stang, the anticline dies away in the region of Sleightholme (35/955101), to be replaced *en echelon* to the south by the small Tan Hill anticline of Rowell & Scanlon (1957). As the main anticline has previously been known only after the locality of the most easterly exposures along the axial line, it was thought desirable to add to the name to delimit the western as well as the eastern end of the structure. It is therefore proposed that the term Middleton Tyas–Sleightholme anticline be adopted.

The southern flank of the anticline is considerably complicated by faulting, and throws of up to 300 feet have been measured. A number of these faults have been mineralised, and are associated with the Swaledale–Arkengarthdale system. It is nevertheless possible to estimate the average dip at about 500 feet per mile, which is somewhat steeper than that of the northern limb.

It has long been considered that the Middleton Tyas–Sleightholme anticline was a pre-Permian structure, and the Primary Survey indicated an unconformable overlap of the Permian across the Upper Limestone Group on the published map. Because of very heavy drift cover, positive proof of this point was not available, and it was not until over sixty years later that convincing evidence was forthcoming from the Scorton bore-hole (45/251999) (Fowler, 1945). The Magnesian Limestone is there represented by no more than two feet of dolomite resting on fifteen feet of basement beds, but this horizon rapidly thickens to the north, south and east. The change is so rapid that the most reasonable explanation is one of overlap of the Permian beds on to a pre-existing ridge of Carboniferous rocks. Very recently, further convincing evidence has come from a bore-hole at Newton Morrell (45/237093), two miles north of Middleton Tyas. A thick basal Permian breccia there rests on beds of the Underset cyclothem, yet only a short distance to the west and south there is abundant evidence of the overlying Main Limestone and succeeding cherty horizons. Clearly, considerable erosion must have taken place before the onset of Permian deposition in the area, and this suggests that formation of the anticline may have been initiated as early as Upper Carboniferous times. There is stratigraphical evidence for the formation of an east–west ridge in the Wensleydale district during the time of deposition of the lower part of the Upper Limestone Group (Wells, 1955a, p. 183). Further evidence of early Upper Carboniferous movement comes from consideration of the beds between the Main and Little Limestones in upper Swaledale, and down-warping associated with movement of the Cotherstone syncline must then have extended southwards to enable the thick Coal Sills Group to be accommodated. So it is suggested that as Hercynian movements appear to have already started by then, at least part of the Middleton Tyas–Sleightholme anticline was initiated as early as Upper Limestone Group times, and that the Coal Measures may never have been deposited in this area.

It is generally agreed that the area now occupied by the Northern Pennines had, by early Tertiary times, been reduced to an almost flat surface by erosion, and that the resulting peneplain was subsequently tilted eastwards by very considerable later Tertiary movement along the Outer Pennine Fault. This fact was realised as early as 1836 by Phillips (p. 139), who noted a universal dip eastwards from the Pennine Fault of between sixty and 100 feet per mile, and it is this tilted peneplain which has been partially dissected to give the topography of today. It is of interest to see what the structure of the area may have been like before this tilting, which is thought to have taken place in comparatively late Tertiary times (Trotter, 1929, p. 167), and a modified structure contour map (Fig. 7) has been constructed by removing the average topographical dip of the area after the method adopted by Reading (1957). An easterly dip of 100 feet per mile was found to be a satisfactory figure, and as this is the same as the value used by Reading, the two maps are again directly comparable.

The suggested early Tertiary structure which emerges after this modification is somewhat better defined than that of the present day. The easterly pitch of the anticline has been entirely removed, and the closure at its western end is now as well marked as that at its eastern end. The Gilling and Whashton domes are again dominant features, and the rather open area along the axis between Byers Hill and Stang now becomes a third well-marked dome centred on Byers Hill. The slightly asymmetrical nature of the anticline is more easily noticed because the flanks of the structure are now parallel. There is a striking similarity, only of course in reverse, to the detail of the structure obtained by Reading when he removed the easterly pitch of the Cotherstone syncline. This, together with their complementary nature, suggests the approximately contemporaneous formation of the two structures by north–south compressive forces, although the Stainmore area is thought to have been a trough of sedimentation in Lower Carboniferous times long before the Middleton Tyas–Sleightholme anticline could have been initiated.

(b) Faults

A statistical analysis of trends shows that there is a marked predominance of faults running between seventy and eighty-five degrees west of north, and a less well-marked peak at sixty-five to seventy degrees east of north, with a broad minimum between thirty degrees west of north and twenty-five degrees east of north, and a narrower minimum between eighty degrees east of north and due east.

The three most important faults in the area all trend roughly west-north-west, and two of them serve as the boundary to the south-western part of the map for some of their length. Although these faults run remarkably straight for miles, a complete reversal of throw is accomplished along the length of each one, and the reversal is in the same direction in all cases. The throw is to the north along the western parts of the faults and to the south along their eastern parts. This state of affairs can arise in a number of ways, but in this instance it is thought that faulting, combined with a little horizontal movement, has succeeded slight folding. If the axis of the fold makes a large angle with the direction of subsequent faulting, it is only necessary for comparatively small lateral movement to take place to effect a marked reversal of throw along the fault. Eller Beck Hush (35/991103), on the North Spanham Fault, has exposed horizontal slickensiding in the region where the throw is in the process of reversal, and this is considered to be positive evidence in favour of the theory. The North Spanham Fault is a continuation of the south branch of the Stainmore Summit Fault carried as far east as Sleightholme Beck by Reading, and is thus the eastern end of an important dislocation which extends for over ten miles.

It has been found, with a better understanding of the stratigraphy, that a number of the faults mapped during the Primary Survey are unnecessary and have been omitted. Several new faults have been recognised, but even so the total number has been somewhat reduced. Two structurally interesting faults are those which bound the Whashton dome. The Feldom Fault, on its south-east margin, is over three miles in length, and its throw to the south-east is over 100 feet for much of that distance. The Kirby Fault, running roughly parallel to, and north-west of this, has a similar throw to the north-west, and the beds between these two faults have been comparatively sharply folded. The striking thing about these faults is the rapidity with which they die out at their north-eastern ends. The Feldom Fault, where it crosses the western end of Whashton village (45/147063), drops its throw from about 130 feet to less than twenty feet in only one third of a mile, this being apparently entirely due to the dying out of the fold between the two faults. So it is evident that at the time the Whashton dome was formed, movement took place along the two faults contemporaneously with the folding. The faults may have been in existence prior to doming, but there is no evidence to show that this was the case. It seems likely that most, if not all, of the faults in the area were at least initiated during the Hercynian folding.

Part of the eastern boundary of the map incorporates the important Darlington Fault, which separates the Trias from beds of the Upper Limestone Group in the south and from the Magnesian Limestone farther north. Fowler (1945), from consideration of sub-surface records, was able to fix its position with considerable accuracy, despite the fact that there are no surface exposures, and the line of the fault has been taken directly from the map reproduced (p. 246) in his paper.

(c) Joints

The first mention of joints and joint directions in the Carboniferous of the Pennines was by Phillips (1836). He published a diagram (p. 98) showing the distribution of eighty-nine readings, about three-quarters of which were taken on the Carboniferous Limestone Series of the Askrigg Block. This diagram shows a strong broad maximum at north-north-west, two subsidiary maxima at east and east-north-east, and minima of zero at north-west by west and north-east by north. Phillips also recognised that these directions were independent of at least all the minor faults. The only other relevant work to have been done in this country was by Wager (1931) and Dunham (1933). Wager described the joint system in the Great Scar Limestone of the Craven district, two sets of joints at right angles being interpreted as shear fractures. Dunham analysed more than 1000 joint readings on the Great Limestone in the Stanhope–Frosterley area of Weardale, and obtained maxima at twenty to twenty-five degrees west of north and sixty to seventy degrees east of north, similar to those of Phillips. These two sets at right angles he also attributed to shear fractures.

Some 400 joint readings were made during the present survey. These readings were nearly all taken on limestones, the majority being on the well-exposed and thick Main Limestone. Analysis indicated three strong maxima, fifty-five to sixty degrees east of north, fifteen to twenty degrees west of north and forty-five to fifty degrees west of north, with a very low minimum at east and a zero minimum at ten to fifteen degrees east of north. These directions evidently bear no relationship to those of the major west-north-west faults, but the first of the maxima does correspond in direction with many of the minor faults, some of which are also mineral veins. It will be noted that the first maximum is exactly at right angles to the bisector of the other two, which are separated by thirty degrees.

In an important work on the joint system of the Palaeozoic beds of the Allegheny Plateau of New York and Pennsylvania, J. M. Parker (1942) has shown that the joints there can be divided into two sets which intersect approximately at right angles. He was also able to sub-divide one set into two groups which intersect at a small angle. Both theoretical and experimental work has shown that this double set can be produced by simultaneous compression and tension acting at right angles. Such an arrangement of stresses will result in the tangential components reinforcing one another, while the normal components, acting in opposite directions, will tend to cancel one another. Variation in the relative values of these components will serve to modify the angle at which the two groups of joints in the set will intersect. So it is evident, from Parker's work, that the joint system of the north-eastern part of the Askrigg Block could have resulted from simultaneous compression and tension acting at right angles. This interpretation would require compression from directions thirty-five degrees west of north and thirty-five degrees east of south, and tension from directions fifty-five degrees east of north and fifty-five degrees west of south. Such stresses correspond closely with the north-west/south-east compression proposed by Wager for the information of the joints of the Craven district, but Dunham considered a north/south compression to be more likely for those of the Alston Block. Reading was unable to find any definitely dominant direction of jointing in the beds of the flexible Stainmore syncline, but there was a marked absence of jointing in a north-north-east direction, which he took as confirmation of a roughly north/south compression. It is evident that much of the transverse folding in this part of the Pennines was produced by a north/south compression, but in practically every case the jointing is at right angles to the bedding, regardless of dip, implying that the joints were formed before and independently of the folds. So it is not necessary to suppose that the compression which produced the folds was from the same direction as that which gave rise to the joint system.

The statistical analysis of Dunham's results does actually show a subsidiary maximum at fifty-five to sixty degrees west of north, and the bisector of this direction and the peak at twenty to twenty-five degrees west of north trends very nearly north-west/south-east. So if this apparently minor peak, as well as the other two, could be shown to be of importance over the Alston Block as a whole, there would then be justification in postulating a roughly north-west/south-east compression (combined with tension at right angles to this) for the formation of the joint system over the Northern Pennines as a whole.

In many of the larger quarries visited during the present survey, the joint surfaces can be followed for considerable distances, and it is a striking fact that the set at fifty-five to sixty degrees east of north are irregular and often curve away as much as ten degrees from their average direction, whereas the other two sets are remarkably even and constant in trend. This is precisely what Parker found on the Allegheny Plateau, and it led him to believe that the irregular set, at right angles to the bisector of the other two sets, originated from tension alone. These tensile joints would have been formed somewhat later than the other two sets, but on the Askrigg Block this second stage of joint formation was doubtless connected with the same period of stresses, all joints having been in existence before the pre-Permian folds were initiated.

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REFERENCES

CARRUTHERS, R. G. 1938. Alston Moor to Botany and Tan Hill: an Adventure in Stratigraphy. *Proc. Yorks. geol. (polyt.) Soc.*, **23**, 236–53.

DAKYNS, J. R. *et. al.* 1890. The Geology of the Country around Ingleborough. *Mem. geol. Surv. U.K.*

———. 1891. The Geology of the Country around Mallerstang. *Mem. geol. Surv. U.K.*

DAVIS, A. G. 1951. *Howchinia bradyana* (Howchin) and its Distribution in the Lower Carboniferous of England. *Proc. Geol. Ass., Lond.*, **62**, 248–53.

DUNHAM, K. C. 1933. Structural Features of the Alston Block. *Geol. Mag.*, **70**, 241–54.

———. 1948. Geology of the Northern Pennine Orefield. Vol. I. Tyne to Stainmore. *Mem. geol. Surv. U.K.*

DUNHAM, K. C. 1950. Lower Carboniferous Sedimentation in the Northern Pennines (England). *XVIII Int. Geol. Congr.*, Pt. IV, 46–63.

FORSTER, W. 1809. *A Treatise on a Section of the Strata from Newcastle-on-Tyne to the Mountain of Cross Fell, in Cumberland.* Alston.

FOWLER, A. 1945. Evidence for a New Major Fault in North-East England. *Geol. Mag.*, **82**, 245–50.

HUDSON, R. G. S. 1924. On the Rhythmic Succession of the Yoredale Series in Wensleydale. *Proc. Yorks. geol. (polyt.) Soc.*, **20**, 125–35.

—— ——. 1938. Part of 'The Geology of the Country around Harrogate'. *Proc. Geol. Ass., Lond.*, **59**, 295–330.

—— ——. 1941. The Mirk Fell Beds (Namurian, E_2) of Tan Hill, Yorkshire. *Proc. Yorks. geol. (polyt.) Soc.*, **24**, 259–89.

KENDALL, P. F. 1911. The Geology of the Districts around Settle and Harrogate. *Proc. Geol. Ass., Lond.*, **22**, 27–60.

—— —— & A. E. WROOT, 1924. *The Geology of Yorkshire.* 2 vols. Privately printed.

MARR, J. E. 1910. In *Geology in the Field.* Jubilee volume of Geol. Assoc., London.

————. 1921. On the Rigidity of North-West Yorkshire. *Naturalist, Lond.*, 63–72.

MILLER, A. A. & J. S. TURNER. 1931. The Lower Carboniferous Succession along the Dent Fault and the Yordale Beds of the Shap District. *Proc. Geol. Ass., Lond.*, **42**, 1–28.

MILLER, H. 1887. The Geology of the Country around Otterburn and Elsdon. *Mem. geol. Surv. U.K.*

PARKER, J. M. 1942. Regional Systematic Jointing in slightly deformed Sedimentary Rocks. *Bull geol. Soc. Amer.*, **53**, 381–408.

PHILLIPS, J. 1836. *Illustrations of the Geology of Yorkshire. Part II. The Mountain Limestone District.* London.

RAISTRICK, A. 1926. The Glaciation of Wensleydale, Swaledale and Adjoining Parts of the Pennines. *Proc. Yorks. geol. (polyt.) Soc.*, **20**, 366–410.

RAYNER, D. H. 1953. The Lower Carboniferous Rocks in the North of England: a Review. *Proc. Yorks. geol. (polyt.) Soc.*, **28**, Part 4.

READING, H. G. 1957. The Stratigraphy and Structure of the Cotherstone Syncline. *Quart. J. geol. Soc. Lond.*, **113**, 27.

ROWELL, A. J. & SCANLON, J. E. 1957. The Namurian of the North-West Quarter of the Askrigg Block. *Proc. Yorks. geol. (polyt.) Soc.*, **51, 1–38.**

TROTTER, F. M. 1929. The Tertiary Uplift and Resultant Drainage of the Alston Block and Adjacent Areas. *Proc. Yorks. geol. (polyt.) Soc.*, **21**, 161–80.

—— ——. 1952. Sedimentation Facies in the Namurian of North-Western England and Adjoining Areas. *Liv. Manch. Geol. Journ.*, **1**, 77–102.

—— —— & S. E. HOLLINGWORTH. 1928. The Alston Block. *Geol. Mag.*, **65**, 433–48.

TURNER, J. S. 1935. Structural Geology of Stainmore, Westmorland, and notes on the late Variscan Tectonics of the North of England. *Proc. Geol. Ass., Lond.*, **46**, 121–51.

————. 1956. Some Faunal Bands in the Upper Visean and Early Namurian of the Askrigg Block. *Liv. Manch. Geol. Journ.*, **1**, 410–19.

VERSEY, H. C. 1927. Post-Carboniferous Movements in the Northumbrian Fault Block. *Proc. Yorks. geol. (polyt.) Soc.*, **21**, 1–16.

WAGER, L. R. 1931. Jointing in the Great Scar Limestone of Craven and its Relation to the Tectonics of the Area. *Quart. J. geol. Soc. Lond.*, **87**, 392–424.

WELLS, A. J. 1955. The Glaciation of the Teesdale–Swaledale Watershed. *Proc. Univ. Durham phil. Soc.*, **12**, 82.

————. 1955a. The Development of Chert between the Main and Crow Limestones in North Yorkshire. *Proc. Yorks. geol. (polyt.) Soc.*, **30**, 177–98.

TABLE III: **Analysis of modes given in Table I**

Calc-alkali Adamellites			Potassic Adamellites			Potash Granite		
Specimen No.	Quartz %	K. Felspar %	Specimen No.	Quartz %	K. Felspar %	Specimen No.	Quartz %	K. Felspar %
124	52	14	125	35	39	131	45	40
127	27	29	133	42	38			
145	30	27	136	36	37			
152	28	27	139	32	40			
168	31	25	141	30	45			
			142	35	39			
197	18	23	151	21	37			
Average of 5	34	24	Average of 7	33	39	Average of 131 and K. Adamellites	35	39

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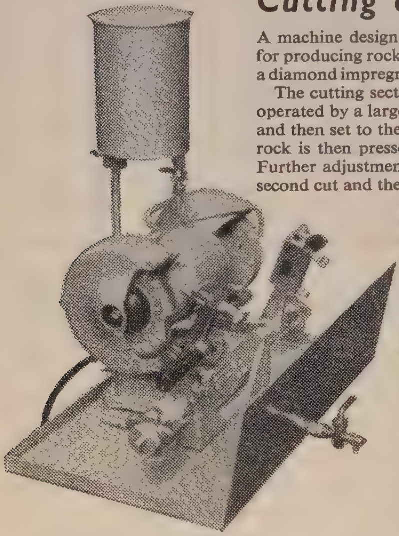

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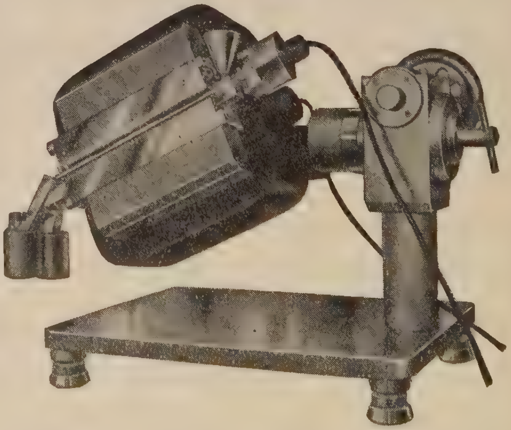

The Palaeogeography of the London Clay Sea

by the late ARTHUR G. DAVIS and GRAHAM F. ELLIOTT

Received 10 April 1957; read 6 December 1957

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ABSTRACT: The London Clay of England (London and Hampshire Basins), Denmark, Germany, Holland and Belgium is briefly described, and the question of its correlation with the Paris Basin Lower Eocene summarised. The fauna and flora of the formation are reviewed as evidence of conditions at the time of its formation. The London Clay Sea is considered to have transgressed from a region of continuous Palaeocene-Lower Eocene sedimentation in the Danish-NW. German area, where it opened north-westwards, over Holland, Belgium and much of the London Basin, then to have transgressed farther over the Hampshire Basin to a Tethyan connection over the English Channel, finally to have retreated eastwards over S. England. The famous tropical flora is considered to have grown on the south-western coasts. The London Basin lower clays are probably represented by Reading Beds in the Hampshire Basin, and the English and Belgian London Clay by non-marine Sparnacian in the Paris Basin. It is recommended that a division into Palaeocene and Lower Eocene is adequate for the pre-Lutetian tertiaries of north-western Europe, instead of stage-names now in use; formation-names are unaffected. It is considered that palynology may yield more reliable datum-lines with these deposits than either facies-faunas or diachronous transgression-planes.

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1. INTRODUCTION

IN 1840 Bowerbank, describing the famous fossil fruits of the London Clay, recognised the significance of the key plant *Nipa*, a tropical palm, and from it suggested the accumulation of the London Clay near the mouth of a great river, which he considered to have flowed from the equatorial regions.

Nearly a century later Reid & Chandler (1933), from the superior vantage-point resulting from an immense accumulation of evidence, both botanical and geological, paid Bowerbank the tribute due to a brilliant pioneer. The systematic part of their monograph is preceded by a detailed introduction which records one of the most fascinating pieces of geological research ever to be undertaken. In it, Bowerbank's original views as to the character of this flora are abundantly justified, but not his river flowing from the tropics, for which the route suggested was blocked by the east to west Tethys Ocean. In the years after the publication of Reid & Chandler's work and before the last war, when one of us (A. G. D.) was determining the horizon of the classic Sheppey flora within the London Clay and the other (G. F. E.) was beginning the serious study of the formation through its rare brachiopods, we conceived the plan of reconstructing the geography of the London Clay Sea, its shores and currents and oceanic connections, so far as this was possible. This study was partially completed and written when the events of the autumn of 1939 began an interruption to our work which was to last for several years. Since then some of the evidence we had amassed has appeared in various scattered publications, including one of our own; on the other hand new discoveries at home and abroad, such as the expected remains of mangroves, and the presence of London Clay in mid-English Channel, permit a better synthesis to be offered now. Whilst all palaeogeography involves a certain measure of speculation beyond strict interpretation of observed facts, we hope that we have kept this to a minimum for the London Clay.

2. THE LONDON CLAY OF SOUTHERN ENGLAND

In southern England the London Clay occurs in the London and Hampshire Basins, two areas of present occurrence now separated by an outcrop of the underlying Cretaceous, across which the London Clay was originally continuous. The clays of the western portion of the London Basin in many respects resemble those of the Hampshire Basin, while those eastwards in the London Basin are similar to the German clays across the North Sea. These facts are essential to an understanding of the London Clay.

(a) The London Basin

The main mass of type London Clay thickens markedly eastwards from a few feet in the west of the Basin until in Essex and Sheppey it is approximately 500 feet thick. Examples of total thicknesses are Great Bedwyn (Wiltshire) 12–15 feet, Aldershot (Hants) 332 feet, Hampstead (London) 403 feet, Ingatestone (Essex) 532 feet and Sheppey 518 feet. To the north at Yarmouth (Norfolk) an incomplete thickness of 310 feet is known, in an area where much has been removed by erosion and the formation is capped by transgressive Crag. This unexpected thickness, so near the feather-edge of the eroded formation, has been considered as possibly due to deposition under isostatic conditions (Boswell, 1916, p. 543): it is significant in view of the summary given below of the German London Clay.

The main lithology of the formation in the London area and eastern districts is of the familiar septarian-coursed stiff clay, but in the western parts of the basin the thinner clays are sandy, as also are the upper beds in the London area. Passage-beds (Claygate Beds in the London area) to the overlying Bagshot Sands are sometimes present.

Wetherell (1836) was the first to notice a vertical change of fauna in the London Clay and proposed three divisions characterised by fossils peculiar to each, viz:

Upper, as at Highgate Archway, with *Murex coronatus*, *Modiolus elegans*, *Nemocardium nitens* (a) and *Glycymeris decussata* (a).

Middle, as at Regent's Park: *Pholadomya margaritacea*, *Nemocardium semigranulatum* (b), *Nautilus regalis* (b), *Nautilus centralis* (b) and *Terebratulina wardenensis*.

Lower, as at Islington and the cliffs between Herne Bay and Whitstable, with *Thyasira angulata* (c) and *Balanocrinus subbasaltiformis*.

Note: (a) abounding in the upper and scarce in the middle;
(b) only found in the middle;
(c) not uncommon in the lower, exceedingly rare in the middle and does not occur in the upper division.

Minor inaccuracies allowed for, it is a very good classification and one of the first English manifestations of palaeontological zoning.

Prestwich (1854) proposed four zones but his classification cannot be said to have improved upon Wetherell's. His fourth zone included London Clay of both London and Hampshire Basins.

Much later, Wrigley (1924) proposed five divisions for the London area and in 1940 gave a review of his work in the intervening years. Wrigley's divisions, which he himself regarded as of necessity artificial, are based upon the succession of species and are correlated with their stratigraphical position above the Basement Bed of the London Clay.

Fifth (uppermost) Division. In its upper fifty feet the London Clay is sandy and laminated, with an approach to the lithology of the Claygate Beds. Fossils are more plentiful than in the main mass of the clay.

Index fossils: *Modiolus elegans*, *Glycymeris decussata*, *Tritonidea londini*, *Athleta nodosus*.

Fourth Division. Stiff clay with normal septaria. At about 300–350 feet above the base.

Index fossils: *Cyprina planata*, *Astarte filigera*, *Corbula globosa*, *Fusinus wetherelli*.

Third Division. Stiff grey clay with normal sphaeroidal concretions. At about 200 feet above the base a more varied fauna has been recognised.

Index fossils: *Pentacrinus oakeshottianus*, *Terebratulina wardenensis*, *Arca impolita*, *Nemocardium semigranulatum*, *Ptychatractus interruptus*, *Streptolathyrus cymatodis*, *Scaphella wetherelli*, *Turricula helix*, *Eopleurotoma simillima*, *Nautilus centralis*. This fauna occupies most of the central thickness of the London Clay.

Second Division. Stiff clays, with flattish septaria, at about 100 feet above the base.

Index fossils: *Balanocrinus subbasaltiformis* and *Thyasira angulata*.

First (*lowest*) *Division.* Stiff clays for about fifty to seventy feet above the Basement Bed. Characteristic fauna unknown. Davis (1928) recorded diatoms from this division at Herne Bay and Colliers Wood, Surrey, and Davis & Elliott (1951) found diatoms and radiolaria at Harwich, Bawdsey and Clacton.

Division 5 is present at the top of the London Clay at Rayleigh (Essex), in London and the surrounding country, and at Bracknell and Wokingham (Berks). At Sheppey the place of division 5 is taken by a stiff clay with a facies-persistence of the fauna of divisions 3 and 4.

Division 4 is known on the southern and western sides of London as far as New Malden and Ashford (Middlesex) with a western extension into Berkshire at Bracknell.

Division 3 appears in the suburbs of London on the north, south and west as far as Potters Bar, Worcester Park and Staines, and may be present in some Essex localities. The fauna of division 2, at about 100 feet above the base, is found on the Essex coast from Holland-on-Sea to Frinton, Aveley (Essex), Herne Bay, Hendon, Beddington (Surrey), and in borings in the Metropolis. It is not known to extend south and west beyond the outskirts of London.

Division 1 seems to occur only south of a line drawn between Harwich and London. Further research may extend these areas but at present the higher divisions seem to extend farther westward than the lower ones.

(*i*) *Westward extension of the London Basin.* In the Aldershot and Basingstoke district distinct faunal differences are seen in sandier sediments, many London species being mixed with others, changing the general aspect of the fauna.

Prestwich (1847, p. 371) remarks that this district is faunally midway between the London and Hampshire areas.

Typical localities: Newnham; Wrigley (1928). Clewett's Green, Old Basing, Cuffell; Prestwich (1847).

Hawkins (1955) in a study of a number of borings in the Enborne Valley found the London Clay was divisible into three sections:

Upper Silts (average 83 feet) with bands of *Turritella* and *Glycymeris*.

Stiff Clays (average 62 feet) with pebble beds, one near the base with beach-battered pebbles up to six inches in diameter, *Glycymeris*, *Turritella*, *Natica*.

Lower Silts (41 feet average thickness). Pebble beds present and local indurations of *Glycymeris*.

This sandy and silty succession is much more like that of the Hampshire Basin, rather than that of the London Basin in which it occurs: a probable emergence-surface was recorded at one level.

Basement Beds. Much work is still required before a complete or general picture can be formed. From east Kent to London a pebble bed is frequent. In this area the Oldhaven Beds and the Basement Bed *s.str*. have been confused. Wrigley & Davis (1924) showed that the Basement Bed (= Oldhaven Beds) east of London is not faunally related to the London Clay but when traced west of London the 'Basement Bed' fauna rapidly changes. A characteristic development is a *Ditrupa* bed and in Hampshire at Nateley and Crondall several typical clay species, particularly *Ficus* and *Cassis*, begin to appear in it. A study of the first occurrences of a species in the London Clay of the eastern area, with the localities in which it is found in the Basement Bed of the west, may throw much light on the problems here discussed. A rich Basement Bed fauna occurs in the Reading district but remains unpublished and another is known from Harefield (Middlesex) (Wrigley, 1930).

The London Clay Basement Beds are probably of different ages in different places, the oldest being the Oldhaven and Blackheath Beds in their type localities. Fossiliferous London Clay Basement Beds are found overlying 'Continental' deposits of the Reading type and this Basement Bed facies-fauna seems to have been confined to situations where the sea was advancing across a sinking coastline (Wrigley, 1940, p. 244).

(b) The Hampshire Basin

In the Hampshire Basin the London Clay is somewhat thinner and much sandier (total thicknesses Southampton 301 feet, Gosport 327 feet), but resembles that of the London Basin in westward thinning (Fordingbridge 118 feet, 60–70 feet maximum in NW. Hants).

However, the clayey facies and orderly succession of faunas present in the type basin are absent in the Hampshire Basin. Here we have facies indicative of shallow seas as compared with the uniformity of the deeper-water conditions of the deposits around London. The deposits are sandy, very variable within short distances and interspersed with pebble beds. This latter feature is absent in the London Clay of the London area but to the southward from Aldershot, pebble beds are distinctly developed. These pebble beds are intraformational 'Basement Beds' marking a renewal of depression and overlaps to the south and west and are of different ages.

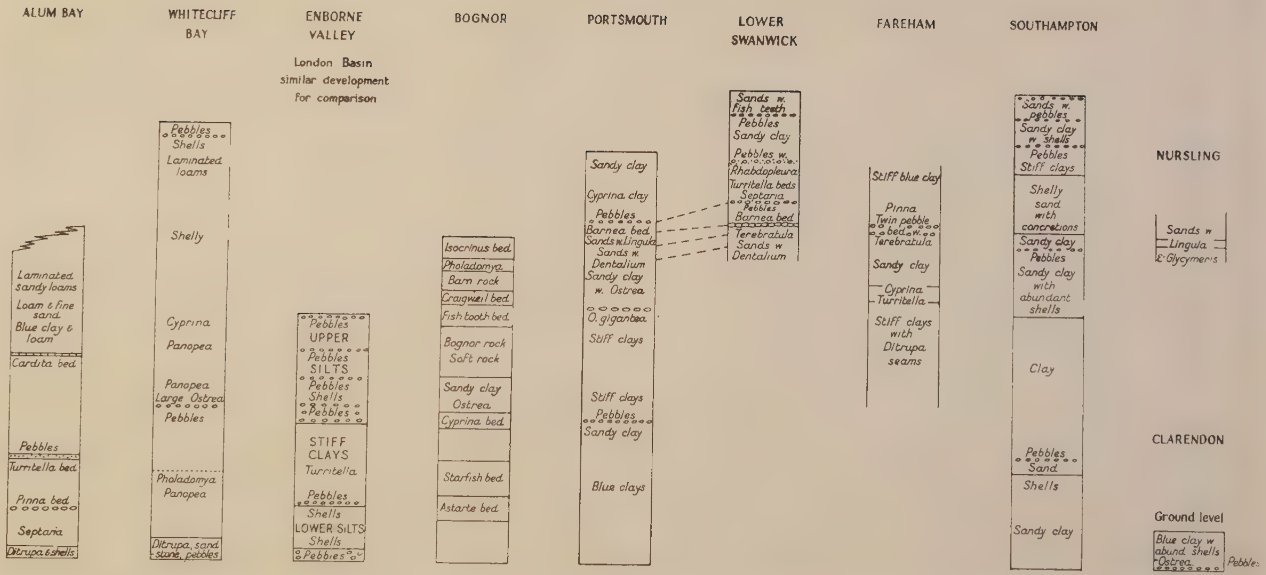

Fig. 1. Selected sections of the London Clay of the Hampshire Basin to show the varied local successions. (Resting on Reading Beds and capped by Bagshot Sands *except* where sections incomplete)

The comparison of sections of London Clay in this basin is a most difficult task. Bognor, Portsmouth, Southampton, Whitecliff Bay, Alum Bay and Enborne (London Basin: similar development for comparison with Hampshire Basin) offer complete successions of the London Clay, but present the utmost variety and discrepancy which at present defy fruitful correlation. In view of this a diagram has been prepared (Fig. 1) showing the most important sections and the important fossil horizons.

The sections have been taken from the following authorities: Alum and Whitecliff Bays (White, 1921), Enborne Valley (Hawkins, 1955), Bognor (Venables, 1929), Portsmouth (Meyer, 1871), Southampton (Reid, 1902), Lower Swanwick (Wrigley, 1949, D. Curry & A. G. Davis MS.), Fareham (Elwes, 1888), Nursling (D. Curry & A. G. Davis MS.), Clarendon (Prestwich, 1850; Elliott, 1945). Faunally there are great differences between the two basins, for some forms which occur in extraordinary abundance in the Hampshire Basin, sometimes forming shell-beds, do not occur in the London area: *Glycymeris brevirostris*, *G. spissa* and *Venericor planicosta* are examples. *Turritella* is extremely rare in the London Basin but occurs in incredible numbers at certain points in the Hampshire Basin. Forms peculiar to the Hampshire Basin are too many to list but included among them are *Ficus smithii*, *Euthriofusus crebrilineus*, *Tibia sublucida*, *Sigatica hantoniensis*, *Athleta denudatus*, *A. depressus*, *Bonellitia subevulsa*, *Ancistrosyrinx pagoda*, *Nucula plagia*, *N. regnorum*, *Ostrea gigantica*, *O. multicostata*, *Astarte clarendonensis*, *Trapezium* sp., *Divaricella* sp., *Pholadomya dixoni* and *P. virgulosa*.

(*i*) *Marginal attenuation of the London Clay.* The development of gravelly beds, extreme variability, the tendency to overlap older deposits and the common occurrence of drift wood (and more rarely of leaves) characterise the London Clay towards its south-western limit (Reid, 1902a). Seams of pebbles occur at several levels, although most usually towards the base. At Verwood (Dorsetshire) the London Clay is reduced to 120 feet and is a sandy facies with a development of tabular ironstones. Crabs, lobsters, *Venericor* and leaves have been found here. A rich molluscan fauna occurs at Holt. The London Clay overlaps the Reading Beds in the district around Cranborne and rests immediately on the Chalk (Reid, 1902a, p. 17).

(c) The English Channel

King (1954) recorded an outcrop of dark grey silty clay which yielded *Lingula*-fragments, probably from the upper part of the London Clay of the silty Hampshire type. This sample (No. 45 from 50° 14½′ N., 1° 24′ W.) was taken with a free drop corer in mid-channel between the Isle of Wight and Cherbourg.

3. THE LONDON CLAY OF THE EUROPEAN MAINLAND

(a) North-west Germany and Denmark

In north-west Germany and Denmark the solid geology is largely covered by glacial and post-glacial accumulations: the Lower Eocene is known from some surface exposures, such as the 'Londonton' of Hemmoor near Hamburg (Gripp, 1925) and the Danish Möler (Madsen, 1928; Andersen, 1937) and from very numerous borings. The latter show a thickness of up to 1000 metres (3280 feet) of marine sediments ranging through the Palaeocene and Eocene: their geology has been studied from different aspects and summarised by various authors including Müller (1937), Staesche (1938), Wirtz (1939), Bettenstaedt (1949), Illies (1949), and Schuh (1952). In this area more than 430 metres (1400 feet) of clayey sediments have been ascribed to the Lower Eocene in the deeper part of the basin (boring Gülze 5, unter-Eocän 1–3; Bettenstaedt, 1949, p. 146; Schuh, 1952, p. 367) resting on marine Palaeocene; marginally southwards the Lower Eocene is thinner and transgressive. Volcanic ash-beds like those of the Danish Möler are met with in the German borings, being referred to the Palaeocene by Müller and placed at the base of the Lower Eocene by later writers. A typical London Clay fauna of various mollusca including *Nautilus*, crabs, sharks' teeth, and *Balanocrinus*, is known principally from Hemmoor (Gripp, 1925). The borings are dated by a microfauna of foraminifera, radiolaria and diatoms: divisions 1–4 of Staesche for the Lower Eocene (Staesche & Hiltermann, 1940). Insect remains are not uncommon in division 1 (Illies, 1949, bibliography). In the boring Cuxhaven 10, the lower portion of the beds ascribed to the London Clay yielded *Terebratulina* and *Balanocrinus* (Gripp, 1925); the latter is not infrequently recorded from the German area.

The palaeogeography of this area has been reconstructed by von Linstow (1922) and Müller (1937) and discussed by later workers. The marginal line drawn for the Lower Eocene sea in north-western Germany and southern Denmark varies according to the particular worker and the evidence available to him, but all agree in indicating a gulf of the ocean opening westwards, with shore-line to the south, east and north-east: in the centre of this gulf marine sedimentation was apparently continuous through the Palaeocene and most of the Eocene: marginally the Lower Eocene is transgressive. In this area there is a fuller development of marine sediments of the Lower Eocene than is preserved elsewhere, unless hidden by the present-day North Sea, and exact correlation of the lower portion of these German sediments equivalent to the type London Clay is so far not possible. The comment of Wrigley (1940) that the lower ash-bearing clays are probably older than the oldest English London Clay we consider correct, though the reason given (absence of ash in the East Anglian clays) scarcely applies, for if the Scandinavian ash had been distributed that far, some trace of it should be found in the underlying Reading Beds.

(b) Holland and Belgium

In Holland the Lower Eocene is masked by alluvium and known from borings: knowledge of it, including earlier work by Van de Geyn (1937) and ten Dam (1944, 1945) has recently been summarised by Pannekoek (1956). It occurs in two areas, a south-western basin of about 140 metres (459 feet) of marine clays, sandy at the top, and a north-eastern basin of over 200 metres (656 feet) of sediments, said to be lagunal below and marine above. In this north-eastern area there is sometimes a basal transgressive conglomerate, and diatoms and thin layers of tuff occur in the lowest 30 metres (98 feet), indicating a marginal relationship to the German Basin. The two Dutch basins indicate continuity near the presumed eastern coastline: in Zuidholland, to the west, absence of Lower Eocene may be due to subsequent erosion.

In Belgium and French Flanders the Argile d'Ypres (Argile de Flandres) attains a westward thickness of more than 140 metres (459 feet) resting on the upper, non-marine, Landenian; eastwards it thins steadily and transgresses on to older rocks. This mass of stiff clay is only sparsely fossiliferous when compared with the English London Clay, but appears in lithology and position to be equivalent. In its upper beds it becomes sandy and passes up into sands with *Nummulites planulatus*, correlated with the Cuisian of the Paris Basin. A detailed summary of the formation, its facies changes and relation to the overlying sandy beds is given by Gulinck & Hacquaert (1954), who also discuss the various correlations proposed for it.

(c) The Paris Basin

The London Clay is but doubtfully represented in the scattered outliers of the north of France near Dieppe. In the Paris Basin, it does not occur at all, the Cuisian Sands with *N. planulatus* resting on the Sparnacian Argile plastique or associated beds. Two alternative views were concurrently held to account for this: the first, that the London Clay is not represented by equivalent strata in the Paris Basin, an opinion already set out by Hébert (1873); and the second, that the London Clay is the facies equivalent of the Cuisian and of the same age, an opinion supported by Dollfus (1880). In 1937 the discovery of a Cuisian fauna with *N. planulatus* above the London Clay in the Isle of Wight (Wrigley & Davis, 1937) led to the recognition of an English Cuisian above the Ypresian and focused attention anew on the Paris Basin. Two reactions were provoked amongst French geologists. Leriche (1937) continued to defend the correlation of the London Clay, Argile d'Ypres, and French and Belgian Cuisian, regarding the differences as largely due to facies changes, and stressing rare records of *N. planulatus* recorded in borings as occurring in the lower, Ypresian, clays. Morellet (1937, 1937a), realising the implications of the new correlation, concentrated attention on the Sables de Sinceny and Tuffeau de Mont-Notre-Dame, thin beds occurring between the Sparnacian Argile plastique and the Sables de Cuise. These were considered as faunally similar respectively to the English Blackheath Beds, a basal Ypresian facies, and to the London Clay itself. This militated against a tentative suggestion that the London Clay might be represented in the Paris Basin by part of the Argile plastique, for which the mammalian evidence was said to give some support (Morellet, 1937a). However, both Sinceny and Mont-Notre-Dame have been shown subsequently to be Cuisian (Abrard & Soyer, 1942; Morellet, 1944). Abrard (1950, pp. 336–7), correlating the top of the Thanetian in the Paris and London Basins, and also the Cuisian with *N. planulatus* in both countries, equated the two sets of beds in between and concluded that the French Sparnacian is the equivalent of the English London Clay and reduced English Sparnacian.

A detailed correlation of the Ypresian–Cuisian of the French and Belgian Basins, with especial reference to the problems discussed above, was given by Feugueur (1951). He concluded that the Ypresian *s.l.* should include a lower substage, the argillaceous Ypresian *s.str.*, and an upper, largely arenaceous Cuisian substage, and that the former does not occur in the Paris Basin, the area of deposition terminating southwards at or near the Artois axis.

Feugueur's observations provoked a spirited reply from Fontaine (1952) maintaining the equivalence of the Belgian Ypresian and French Cuisian, and discounting the postulated rôle of the Artois axis; he admitted, however, that the earliest Ypresian deposits of the London and Belgian Basins should be a little older than the Sables de Cuise and hence contemporaneous with continental deposits in the Paris and Hampshire Basins.

We consider that in the Paris Basin, during the time when the London Clay was accumulating elsewhere, part of the Argile plastique was accumulating in a non-marine environment (cf. Wrigley & Davis, 1937, pl. 18, alternative correlation; Morellet, 1937a; Abrard, 1950; and Le Calvez & Feugueur, 1957, correlation-table, p. 749). The blurring by facies-changes of almost all exact means of correlation, palaeontological and lithological, is further commented on below, in discussing the diachronous nature of the type London Clay in its own basin.

4. THE FOSSILS OF THE LONDON CLAY

The evidence of fossils, correctly interpreted ecologically as well as stratigraphically, is extremely important for palaeogeography. The following paragraphs briefly review the various groups occurring in the London Clay.

(a) Invertebrates

(*i*) *Mollusca*. These are the commonest fossils in British Tertiary sediments, and upwards of 150 genera have been recognised in the London Clay. Of these eighty genera are known in the Palaeocene of Denmark, Belgium and France (the 'northern forms' of Davies (1934–5)), twenty-six are both Tethyan and northern, and of exclusively Tethyan genera there are twenty or more. The remainder are forms of no obvious significance or of genera which make their first appearance in the London Clay. Both generically and in individuals the so-called northern forms greatly outnumber the Tethyan forms; a London Clay without the former would be almost a barren formation. Amongst them are a number of so-called cold genera, namely, *Cyprina*, *Astarte*, *Pholadomya*, *Thyasira* (*Axinus*), and *Aporrhais*, some of which are widespread in the London Clay.

Opinion is not unanimous as to the value of mollusca as indicators of climate, particularly those which have a considerable geological history and have become adaptable to climatic changes (cf. Chavan, 1947, 1950). An unequivocal instance of a tropical mollusc in the London Clay fauna is afforded by the discovery of *Enigmonia bognorensis* Wrigley (1936) associated with the plant *Nipa* at Bognor and Highgate. The type species of *Enigmonia* lives on the immersed roots and leaves of mangroves and *Nipa* on the shores of Borneo, Malaya, India and North Australia. In recent years our knowledge of the London Clay mollusca has been greatly enhanced by the studies of special groups by the late Mr. Arthur Wrigley: Fusinidae 1927, Muricidae 1930a, *Sassia* 1932, Cassididae 1934, Cancellariidae 1935, Strombidae and Aporrhaidae 1938, *Surculites* 1939, Trichotropidae 1942, *Eulima* 1944, Ampullinids 1946, Naticidae 1949a, *Siphonalia* and *Pseudoneptunea* 1953.

Similar studies of the Lamellibranchia have been commenced by Tremlett: Cardiidae (1950), Veneridae (1953); the Cypraeacea have been dealt with by Schilder (1929) and *Teredo* by Wrigley (1930). The Pteropoda are at present being studied by Mr. D. Curry.

(*ii*) *Brachiopoda*. The brachiopods of the London Clay (Elliott, 1955) are relatively few in numbers and in species, but of considerable interest in their distribution. With the exception of a unique specimen of *Argyrotheca*, they are as follows: *Terebratulina*, confined to and locally abundant in the London Basin; *Lingula*, occurring not uncommonly in both basins; *Discinisca* spp. (rare) and *Terebratula* (very locally abundant) confined to the Hampshire Basin.

Terebratulina wardenensis Elliott occurs rarely in the lower stiff clays of the London Basin, associated with *Balanocrinus subbasaltiformis* (Miller), in north-east and south Essex, north Kent, and the London area (Wrigley, division 2). There is also a probable record of it, with *Balanocrinus*, from Germany (Gripp, 1925; Elliott, 1948). It occurs at many localities in the middle stiff clays of the London area (Wrigley, division 3) and finally appears at the top of the formation at Sheppey, still in stiff clays. Present-day species of the genus are distributed in most seas, and may be described as cool-temperate. In the London Clay *T. wardenensis* is a northern species, confined to the stiff clay facies.

Lingula is now distributed along tropical and subtropical muddy shorelines. In the London Clay *L. tenuis* J. Sowerby has been found abundantly and of good size at certain localities in the Hampshire Basin: the London Basin specimens are smaller and much less common, and it may be taken as a probable southern species.

Discinisca is now another inhabitant of warm shallow waters. *D.* spp. occur rarely in the Hampshire London Clay (though *D. ferroviae* Muir-Wood occurs in the underlying Woolwich and Blackheath Beds in the London Basin).

Terebratula hantonensis Muir-Wood was found abundantly at one Hampshire locality only, with rare records of single specimens in the same district. It was probably a Tethyan immigrant, though there is nothing in the nature of the species itself to supply evidence for or against this.

The evidence of the brachiopods may therefore be summarised as indicating the two connections, southern and northern, of the London Clay Sea.

(*iii*) *Polyzoa*. In the London Basin chiefly associated with the stiff clay facies. They are found with drift timber and were probably a floating fauna but they also occur in lenticular drifts of shelly material. In the sandy facies they may be plentiful but belong to only two or three species.

In the Hampshire Basin, polyzoa are mainly found in the *Pinna* and oyster reefs or pebble beds as at Bognor, Clarendon, Alum Bay, Lower Swanwick and Fareham. Gregory (1893) described some London Clay polyzoa but a large number remain undescribed. Lists have been published for the London Basin by Davis (1928, 1936) and Wrigley (1940) and for the Hampshire Basin by Venables (1929) and Thomas & Davis (1949).

The polyzoa of both basins are related to those of the warm seas of the present-day Indo-Pacific.

(*iv*) *Annelida*. *Ditrupa plana* is an abundant form in both basins, and whilst tolerant of any facies it only forms beds in the littoral and sandy facies.

Rotularia, an extinct genus, is generally but sporadically distributed in the middle and upper parts of the London Clay in both basins, being abundant in the sandy facies at Bognor, Wokingham, Bracknell and Highgate. It is absent from the Basement Beds and also from the lower part of the London Clay, excepting Clarendon and Alum Bay (Wrigley, 1951).

Sclerostyla is found in the sandy facies while *Protula* and *Serpula* are found in the clayey facies.

(*v*) *Ostracoda*. Twenty-one species have been recorded by Davis (1928, 1936) from Sheppey and London; Bowen (1953) records fourteen species from Enborne.

Ostracoda are rare compared with other groups in the London Clay and favour the clayey facies in both basins. *Cytheridea mülleri* although rare in the clayey facies is much commoner in the sandy facies of the Hampshire Basin. It is an adaptable form, for it occurs in extraordinary profusion in the extensive Woolwich Beds in the London area and in the Blackheath Beds.

(*vi*) *Foraminifera*. These are abundant in the clayey facies and less abundant in the sandy: ref. Sherborn & Chapman (1886), Davis (1928, 1936), Bowen (1954).

About 120 species are known from the London Basin while seventy-three are recorded (but in much fewer numbers) in the Hampshire Basin, and of the latter total forty-two species are common to both basins. Bowen concluded from his studies that the foraminifera of the London Clay are of little use as palaeoecological indicators or as indices for a zonal classification of the formation. The commonest foraminifer of the London Clay of the London Basin is *Marginulina wetherellii* Jones (= *M. enbornensis* Bowen). It occurs in hundreds in most samples from Sheppey or London; in Bowen's sampling of the Hampshire Basin he only recovered four examples.

(*vii*) *Miscellaneous Invertebrate Groups*. The London Clay has yielded various invertebrate remains besides those discussed above.

Insect remains are known from Bognor (Hampshire Basin) and Denmark, and suggest proximity to the shore-line.

Crustacea, particularly crabs, are not uncommon: some of these, as also with the cirripedes which are locally abundant, may have been associated with floating timber.

Echinoids and asteroids are small and the former dwarfed by the muddy conditions. Holothurian spicules are known. The crinoid *Balanocrinus subbasaltiformis* (Miller) is of interest. In England it is confined to a particular horizon in the stiff clays of the London Basin, occurring at about 100 feet above the base in the London area (Wrigley, division 2) and similarly in north Kent, and south and north-east Essex. In north-west Germany it is not uncommonly recorded from the Lower Eocene Clays; we cannot ascertain from the literature if these occurrences are approximately on a single horizon or not. In England it is a northern, presumed cool-water, immigrant of limited stratigraphic range.

Small single corals occur locally at e.g. Sheppey, Clarendon, etc. *Graphularia* sp. is common. Sponge spicules have been recorded.

The above are all minor elements in the fauna; there is nothing which conflicts with the picture of the London Clay Sea as muddy, of varying depth, with warm littoral and surface waters, and cooler water in the deeper parts of the basin.

(b) Vertebrates

(*i*) *Pisces.* Fish remains are very abundant, particularly at Sheppey, where at an early date they caught the attention of Lhuyd (1699). They are represented by skulls, carcases and isolated teeth. Eighty per cent of the remains consist of Odontaspid and Lamnid teeth. Isolated Odontaspid teeth occur everywhere in the London Clay. Sheppey and Bognor are the only localities where extensive fish faunas have been collected. About forty genera have been described and in this fauna the general warm water character is recognisable. Since Dr. E. Casier of Brussels is making a re-study of the London Clay fishes his results will be awaited with some interest (Casier, in preparation). A recent study of otoliths (Stinton, 1957) adds considerably to our knowledge of London Clay teleostean fishes.

(*ii*) *Reptilia.* The Chelonia are well represented by ten species of marine turtle from Sheppey, Harwich and Bognor, *Argillochelys subcristata* and *Lytoloma longiceps* being the more usual forms present at Sheppey. Five species of marsh tortoise, *Emys*, occur at Sheppey, while the remaining reptiles are represented by *Crocodilus* (two species) and a large sea snake *Palaeophis toliapicus.* This evidence suggests warm conditions.

(*iii*) *Aves. Argillornis*, *Odontopteryx*, *Halcyornis*, *Dasornis* and *Lithornis* have occurred at Sheppey only, in the form of crania, sternum and leg bones. Most of the specimens are unique and fresh finds have not been made for many years.

Fragments and leg bones which have been referred to Gallinaceous birds have been found in some numbers at Sheppey and Bognor.

(*iv*) *Mammalia. Hyracotherium* is known from the higher part of the London Clay at Sheppey and from the lower part at Herne Bay and Harwich and in the basal pebble bed at Kyson, Suffolk.

Coryphodon has a similar distribution at Sheppey and Harwich. There are no records of mammalia in the intervening episodes of the London Clay nor are they known from the Hampshire Basin.

Both *Hyracotherium* and *Coryphodon* occur earlier in England in the Woolwich Beds, Blackheath Beds and the Basement Bed of the London Clay.

(*v*) *The Pterobranch Rhabdopleura.* Of especial interest is the fossil occurrence of the pterobranch *Rhabdopleura eocenica* Thomas & Davis (1949), which is found encrusting pebbles in the London Clay at Lower Swanwick, Hants, the only known locality.

The genus is widely distributed at the present day, ranging from West Greenland in the north to the Antarctic in the south and New Zealand in the east. It lives at depths varying from 2 to 550 fathoms and is found adhering to pebbles, corals, etc.

(c) The Flora

The flora of the London Clay, apart from a micro-flora mostly of diatoms, is represented almost entirely by fossil fruits, mostly of dicotyledons, with a few palms and conifers. The diatoms characterise the lowest beds of the stiff clays of the London Basin (Davis & Elliott, 1951) and indicate a correlation with the lower clays in the German Basin. The fruits have been recorded as occurring sparingly at many localities, at different levels in the formation, but the great bulk have been collected from the sea-cliffs of the Isle of Sheppey, from the upper beds of the London Clay. These fossils are concentrated on the beach by the wasting of the cliffs, but it is probable that they occur in exceptional abundance there, for the other coastal sections have yielded relatively few. The profusion of *Teredo*-bored wood, rarely determinable, and associated marine fossils at Sheppey, indicates drifted accumulation in the sea.

Reid & Chandler (1933), who described the flora, concluded that its affinities were overwhelmingly with the modern tropical flora of the Indo-Malayan region, 73% of the living genera to which London Clay genera are related now occurring there. (See also Edwards (1936).) They considered that in London Clay times, in what is now southern England, the flora, which shows signs of stunting, was living at its northernmost limit. A uniform climate with suitable balance between precipitation and evaporation, suitable seasonable distribution of rainfall, frostless winters, and a mean annual temperature of about 70° F., considered necessary for the growth of this tropical flora, was explained by them as probably due to the effect of warm currents in the Tethys, along whose shores the flora migrated. It may be added that such a climate is not unlikely for the Eocene of this area, for the present sharply zoned latitudinal climatic belts are geologically abnormal and are a legacy from the late Tertiary orogeny and Pleistocene glaciation. Finally Reid & Chandler drew attention to a modern account (Moseley, 1879) of drifted wood and fruits in Indonesian seas, seventy miles from land, which indicated the very conditions under which the drifted waterlogged flora is supposed to have sunk to fossilisation. In this connection it should also be noted that off the present-day Mississippi delta (Shepard, 1956) bottom-set clays containing both open-marine shells and wood from the river extend in one direction to within six miles of one of the delta mouths. As already mentioned, *Nipa*, the key plant of the flora, is abundant in the London Clay: its modern habitat is in the coastal and estuarine swamps of Indonesia and Malaya where it alternates with, or is associated with, mangroves. The absence of these latter in the London Clay was commented on by Reid & Chandler (1933, p. 62), but they have since been found (Chandler, 1951).

Subsequent to this main work, the origin and migration of the London Clay flora have been briefly discussed by Chandler (1954) and Edwards (1955), and further studies by Miss Chandler on much new London Clay material await publication. The temperate elements in the flora have been commented on by Brett (1957) in a paper on fossil wood. Richards (1952, p. 154) in a text-book study of modern tropical rain-forests agreed with Reid & Chandler's conclusions on the tropical nature of the London Clay flora, and considered that further investigation of the climatic limits of rain-forest and other related plant communities might make possible a more precise definition of the London Clay climate. He added that although fruits and seeds are valuable in indicating taxonomic affinities, a statistical study of leaf sizes, etc., indicated the physiognomy of a flora, which with modern plants was a very sensitive index of environment.

Minor details apart, the largely lowland tropical character of the London Clay flora, with the accumulation of its wood, fruits and seeds relatively close to land as drifted material in a shallow muddy sea, remains one of the most important pieces of evidence for the palaeogeography of the formation.

5. THE MAP, AND AN INTERPRETATION OF THE HISTORY OF THE LONDON CLAY SEA

The map (Fig. 2) shows the maximum extension of the London Clay Sea. The deepest part of this sea of which we now have evidence, or at any rate the region of maximum sedimentation, appears to have been in the 'basinal' part of north-west Germany, where maximum thicknesses of marine argillaceous sediments followed conformably on marine Palaeocene. Along the line of the present Skagerrak near the Scandinavian land-mass volcanic eruptions showered ash into the sea over a wide area, now Denmark and north-west Germany. It is uncertain if there was Thulean volcanic activity at the same time (Davis & Elliott, 1951). Marginally this sea then transgressed over wide areas of what is now the North Sea Basin: Germany, Holland, Belgium and England (London Basin), over both Palaeocene and basal Lower Eocene deposits, and sometimes on to older rocks. The areas of the present-day Paris and Hampshire Basins were not invaded, and remained in a Sparnacian–Reading Beds facies. In the London Basin this sea is represented by the transgressive Oldhavens and shelly London Clay basement beds, then by the stiff clays of East Anglia, North Kent and Wrigley's divisions 1 and 2 of the London area. This sea opened to the north, with cool-water connections; with it came first a diatom-flora, then *Balanocrinus subbasaltiformis* and *Terebratulina wardenensis*, all links with the German area, and the first two confined to these lower beds. It is worth noting that even in the deposits of this older clay, before the Tethyan connection about to be discussed, tropical fruits occur, including occasional *Nipa*: they must already have been growing near the south-western coast (Edwards (1955), on the origin and migration of the London Clay flora). Next, somewhere about the time of the lower middle clays of the London area, the sea transgressed south-westwards over the Hampshire Basin Reading facies, and its waters merged with those of a branch or connection of the Tethys over the present-day English Channel, where London Clay has been recorded midway between England and France (King, 1954). In this advance over the clayey Readings the London Clay Basement Bed is often marked by the worn *Ditrupa*.

We see no evidence, in London Clay times after the Blackheath pebble-accumulations, for the Wealden island of various writers on the Eocene, and agree with Wrigley (1940, p. 243) as to the south-western origin of the Hampshire Basin London Clay pebble-beds. The Tethyan connection brought a warm current which spread warm-water mollusca, brachiopoda and polyzoa, and other marine organisms, first in the Hampshire Basin and then to the London Basin, where some of the mollusca are most abundant at the top of the formation. Along the flats of the south-western and southern coasts, now removed by denudation, the tropical flora grew in profusion. There is no direct evidence of a single large river in this direction during London Clay times, and we feel that if several smaller streams carried the wood and fruits out to sea, the Tethyan current would drift them many miles from the coast. In Upper London Clay times the sea regressed eastwards, sandy Bagshot sedimentation spread from the west, and probably the south, the upper clays of the London area became sandy, and much of the fauna now known from the middle clays of the London area shifted eastwards, to be preserved in the same facies at Sheppey. Perhaps the London Clay of Sheppey represents the old sea-floor beneath some intercurrent portion of the sea, where drifted material such as fruits and wood of all sizes, bored and encrusted, and occasionally with land animal carcases, accumulated until waterlogged, when it sank to be preserved with remains of fishes and birds from the surface and the shells and other creatures of the sea-floor. Finally Bagshot sedimentation spread over the whole area, and the story of the London Clay Sea ended.

6. NOTE ON THE CLASSIFICATION OF THE LOWER EOCENE

It has long been known that, in the classic lower Tertiaries of France, Belgium and England facies-changes are the rule and not the exception, and that the whole complex of deposits evidences frequent changes between marine, brackish and continental environments over very limited areas;

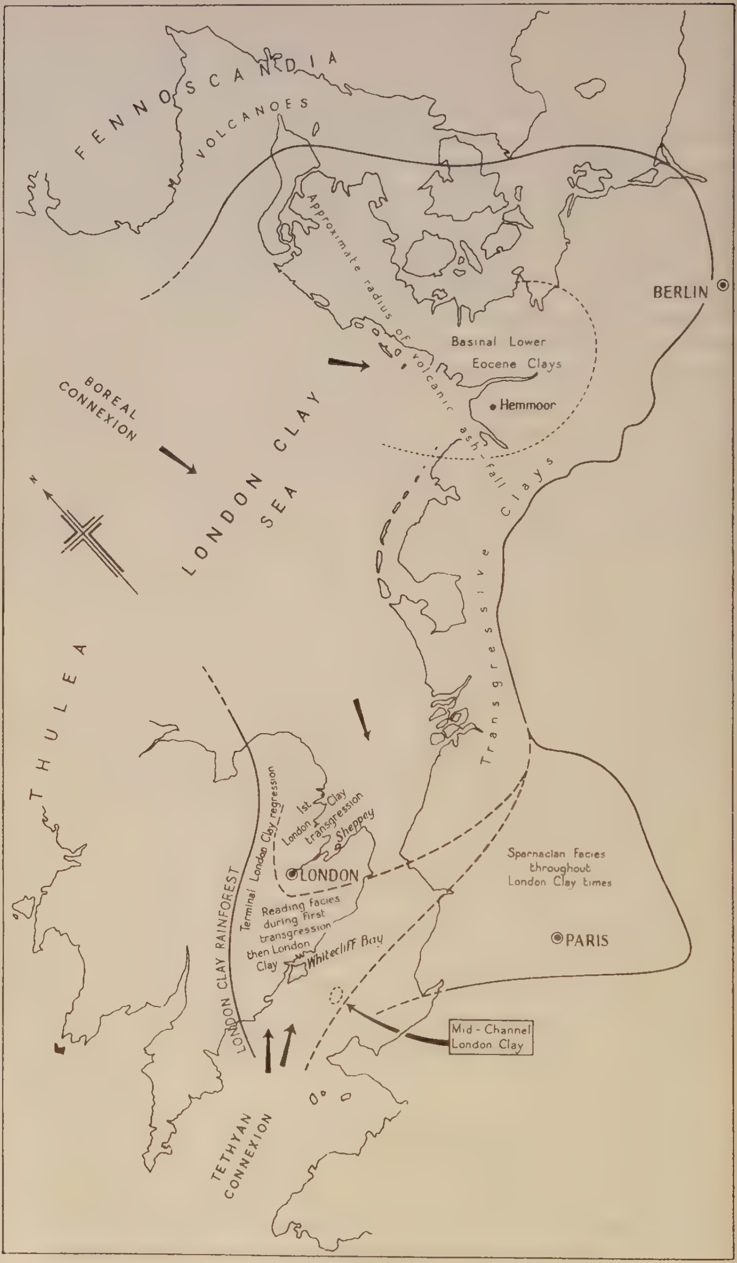
FENNOSCANDIA
VOLCANOES
Approximate radius of volcanic ash-fall clays
BERLIN
Basinal Lower Eocene Clays
Hemmoor
BOREAL CONNEXION
LONDON CLAY SEA
N
THULEA
Transgressive Clays
Terminal London Clay regression
1st. London Clay transgression
Sheppey
LONDON
Reading facies during first transgression then London Clay
Whitecliff Bay
LONDON CLAY RAINFOREST
Sparnacian Facies throughout London Clay times
PARIS
Mid-Channel London Clay
TETHYAN CONNEXION

Fig. 2. The London Clay Sea

these ideas were perhaps most strongly stressed by Stamp (1921). The stage-names devised for these deposits are for the most part taken from lithologically or palaeontologically conspicuous, but incomplete, successions in one basin which attracted the attention of the early geologists. There is rarely agreement over their application in other basins, and the modern worker struggles with an overlapping terminology as confusing as the facies-changes themselves. Even the London Clay, the most conspicuous marine incursion of all, is basally and terminally diachronous in its type basin and its correlation abroad disputed. If time-planes are to be sought in these Palaeocene–Lower Eocene deposits, they will be found probably not with the aid of conventional facies-bound fossils, nor with diachronous transgression-planes, but with spores and pollen, which settle on land and swamp and sea alike. London Clay samples examined by one of us (G. F. E.) certainly contained such a palynflora, though it should be noted that derived Palaeozoic and Mesozoic spores were conspicuous. This problem is commended to those able to undertake it. Meanwhile, for the age-grouping of the whole complex of local lithological formations we suggest that in north-western Europe a simple division into Palaeocene and Lower Eocene is adequate: in England the former would comprise the Thanet Beds and widespread sandy bottom bed of the Woolwich and Reading Beds (Wrigley, 1949b), the latter all succeeding deposits up to and including the Lower Brackleshams with *N. planulatus*. There is little disagreement over the French and Belgian equivalents of the Thanets, but the range of *N. planulatus* in these countries needs checking against all other evidence so far as this is possible. The Germans appeared to have reached the same point of view with their own basinal sediments but for the opposite reason, because of the paucity of detail there available. In this way the terms Cuisian, Landenian, Londinian, Sparnacian and others can be allowed to lapse, and be remembered as indicating a 'stage' in our understanding of the deposits to which they apply, rather than geological stages as used elsewhere in the geological column.

REFERENCES

ABRARD, R. 1950. *Géologie Régionale du Bassin de Paris.* Paris.

——— & R. SOYER. 1942. Découverte de *Nummulites planulatus* Lmk. dans les Sables de Sinceny (Aisne). *C.R. Acad. Sci. Paris*, **214**, 677–8.

ANDERSEN, S. A. 1937. De vulkanske Askelag; Vejgennemskaeringen ved Olst og deres Udbredelse; Danmark. *Danm. geol. Unders.*, II Raekke, no. 59.

BETTENSTAEDT, F. 1949. Paläogeographie des nordwestdeutschen Tertiär mit besonderer Berücksichtigung der Mikropaläontologie. *Erdöl und Tektonik in Nordwestdeutschland*, 143–72. Hanover.

BOSWELL, P. G. H. 1916. The Stratigraphy and Petrology of the Lower Eocene deposits of the North-eastern Part of the London Basin. *Quart. J. geol. Soc. Lond.*, **71**, 536–91.

BOWEN, R. N. C. 1953. Ostracoda from the London Clay. *Proc. Geol. Ass., Lond.*, **64**, 276–92.

Bowen, R. N. C. 1954. Foraminifera from the London Clay. *Ibid.*, **65,** 125–74.

Bowerbank, J. S. 1840. *A History of the Fossil Fruits and Seeds of the London Clay.* London.

Brett, D. W. 1957. Fossil Wood of *Cercidiphyllum* Sieb. and Zucc. from the London Clay. *Ann. Mag. nat. Hist.*, **12** (9), 657–65.

Casier, E. (*in preparation*). 'Les Poissons du London Clay.' *Brit. Mus.* (*Nat. Hist.*).

Chandler, M. E. J. 1951. Note on the Occurrence of Mangroves in the London Clay. *Proc. Geol. Ass., Lond.*, **62,** 271–2.

———. 1954. Some Upper Cretaceous and Eocene Fruits from Egypt. *Bull. Brit. Mus.* (*nat. Hist.*) (*a*), **2** (4), 147–87, pls. 10–16.

Chavan, A. 1947. L'évolution des faunes marines de Mollusques dans le nord-ouest de l'Europe, de la fin du Crétacé à celle de l'Éocène. *Bull. Soc. géol. Fr.* (5), **16,** 193–212.

———. 1950. Remarques sur la signification climatique des Mollusques marins fossiles. *Ibid.* (5), **19,** 507–12.

Dam, A. ten. 1944. Un coup d'oeil sur la structure du Bassin éocène des Pays-Bas. *C.R. Soc. Géol. Paris*, 1944, No. 11, 128–30.

———. 1945. De structuur van de Palaeocene en Eoceene Bekkens in Nederland. *Geol. en Mijnb.*, **7,** 38–43.

Davies, A. M. 1934–5. *Tertiary Faunas.* London.

Davis, A. G. 1928. The Geology of the City and South London Railway Clapham–Morden Extension. *Proc. Geol. Ass., Lond.*, **39,** 339–52.

———. 1936. The London Clay of Sheppey and the location of its fossils. *Ibid.*, **47,** 328–45.

———. 1937. Additional Notes on the Geology of Sheppey. *Ibid.*, **48,** 77–81.

——— & G. F. Elliott. 1951. The London Clay of Coastal Suffolk and Essex. *Geol. Mag.*, **88,** 329–38.

Dollfus, G. F. 1880. Essai sur l'extension des terrains tertiaires dans le Bassin Anglo-Parisien. *Bull. Soc. géol. Normandie*, **6,** 584–605.

Edwards, W. N. 1936. The Flora of the London Clay. *Proc. Geol. Ass., Lond.*, **47,** 22–31.

———. 1955. The Geographical Distribution of Past Floras. *Advanc. Sci.*, **12** (46), 165–76.

Elliott, G. F. 1945. Faunal Horizons in the London Clay of Clarendon, Wilts. *Proc. Geol. Ass., Lond.*, **56,** 151–2.

———. 1948. Distribution des Brachiopodes en Espèces et ses Causes, illustrée par les térébratulinidés de l'Éocène de l'Europe occidentale. *Bull. Soc. géol. Fr.* (5), **17,** 67–80.

———. 1955. Additions to the British Eocene Brachiopod Fauna. *Geol. Mag.*, **92,** 168–72.

Elwes, J. W. 1888. Sections opened on the new Railway from Fareham to Netley. *Pap. Hampsh. Fld. Cl.*, **2,** 31–9.

Feugueur, L. 1951. Sur l'Yprésien des Bassins français et belge, et l'age des Sables d'Aeltre. *Bull. Soc. belg. Géol. Pal. Hydr.*, **60,** 216–42.

Fontaine, A. 1952. Les transgressions yprésienne et lutétienne. *Ibid.*, **61,** 91–100 (reply by Feugueur, 100–2).

Furon, R. & R. Soyer. 1947. *Catalogue des Fossiles Tertiaires du Bassin de Paris.* Paris.

Geyn, W. A. E. van de. 1937. Das Tertiär der Niederlände mit besonderer berücksichtigung der Selachierfauna. *Leid. geol. Meded.*, **9,** 177.

Gregory, J. W. 1893. On the British Palaeogene Bryozoa. *Trans. zool. Soc. Lond.*, **13,** 219–79.

Gripp, K. 1925. Über das Alttertiär von Hemmoor, ein Beitrag zur Stratigraphie Nordwest-Deutschlands. *Jber. niedersächs. geol. Ver.*, **17,** 127–38.

Gulinck, M. & A. Hacquaert. 1954. L'Éocène, in *Prodrome d'une Description Géologique de la Belgique*, ed. P. Fourmarier. Liège.

Hawkins, H. L. 1955. The Eocene Succession in the eastern part of the Enborne Valley, on the borders of Berkshire and Hampshire. *Quart. J. geol. Soc. Lond.*, **110,** 409–30.

HÉBERT, E. 1873. Comparaison de l'Éocène inférieur de Bassin de Paris, de Belgique et d'Angleterre. *Bull. Soc. géol. Fr.* (3), **2,** 27–31.

ILLIES, H. 1949. Die Lithogenese des Untereozäns in Nordwestdeutschland. *Mitt. min.-geol. (St.) Inst. Hamb.*, **18,** 5–44.

KING, W. B. R. 1954. The Geological History of the English Channel. *Quart. J. geol. Soc. Lond.*, **110,** 77–101.

LE CALVEZ, Y. & L. FEUGUEUR. 1957. L'Yprésien Franco-Belge: essai de correlation stratigraphique et micropaleontologique. *Bull. Soc. géol. Fr.* (6), **6,** 735–51.

LERICHE, M. 1937. Sur l'Yprésien marin des Bassins anglais, belge et parisien, et sur les Sables d'Aeltre. *C.R. Soc. Géol. Paris*, No. 16, 229–31.

———. 1942. Sur les Sables et Tuffeau de Mont-Notre-Dame (Aisne) et sur leurs equivalents dans le bassin belge. *C.R. Soc. Géol. Paris*, No. 10, 92–3.

LHUYD, E. 1699. *Lithophylacii Britannici Ichnographia, etc.* London.

LINSTOW, O. VON. 1922. Die Verbreitung der tertiären und diluvialen Meere in Deutschland. *Abh. preuss. geol. Landesanst*, n.f., **87.**

MADSEN, V. AND OTHERS. 1928. Summary of the Geology of Denmark. *Danm. geol. Under.*, **5** (4), 66–73.

MEYER, C. J. A. 1871. On Lower Tertiary Deposits recently exposed at Portsmouth. *Quart. J. geol. Soc. Lond.*, **27,** 74–89.

MORELLET, L. 1937. Le problème du synchronisme des assises de l'Éocène inférieur dans les bassins anglais, parisien et belge. *C.R. Soc. Géol. Paris*, No. 13, 197–8.

———. 1937a. A propos du 'London Clay'. *Ibid.*, No. 14, 211–12.

MORELLET, L. & J. 1944. L'age du Tuffeau de Mont-Notre-Dame (Aisne). *Ibid.*, No. 13, 156–8.

MOSELEY, H. N. 1879. *Notes by a Naturalist on the 'Challenger'*. London. (2nd ed. 1892.)

MÜLLER, T. 1937. *Das Marine Paläozan und Eozän in Norddeutschland und Sudskandinavien.* Berlin.

PANNEKOEK, A. J. 1956. Eocene, in *Geological History of the Netherlands*, ed. N. Pannekoek. The Hague, 57, 60.

PRESTWICH, J. 1847. On the probable age of the London Clay, and its relations to the Hampshire and Paris Tertiary Systems. *Quart. J. geol. Soc. Lond.*, **3,** 354–377.

———. 1850. On the Structure of the Strata between the London Clay and the Chalk in the London and Hampshire Tertiary Systems. *Ibid.*, **6,** 252–81.

———. 1854. On the thickness of the London Clay, on the relative position of the fossiliferous beds of Sheppey, Highgate, Harwich, Newnham, Bognor, etc.; and on the probable occurrence of the Bagshot Sands in the Isle of Sheppey. *Ibid.*, **10,** 401–19.

REID, C. 1902. The Geology of the Country around Southampton. *Mem. geol. Surv. U.K.*

———. 1902a. The Geology of the Country around Ringwood. *Ibid.*

REID, E. M. & M. E. J. CHANDLER. 1933. *The London Clay Flora.* London.

RICHARDS, P. W. 1952. *The Tropical Rain Forest: an Ecological Study.* Cambridge.

SCHILDER, F. A. 1929. The Eocene Amphiperatidae and Cypraeidae of England. *Proc. malac. Soc. Lond.*, **18,** 298–311.

SCHUH, F. 1952. Beitrag zur Alttertiär-stratigraphie Nordwestdeutschlands, ausgehend von der Untersuchung einer fast geschlossenen Bohrkernfolge von über 300 m. aus dem nordwestlichen Mecklenberg. *Geol. Jber., f.* 1950. *Geol. Landes. Bund. Deutsch.*, **66,** 313–76.

SHEPARD, F. P. 1956. Marginal Sediments of Mississippi Delta. *Bull. Amer. Ass. Petrol. Geol.*, **40,** 2537–623.

SHERBORN, C. D. & F. Chapman. 1886. On some Microzoa from the London Clay exposed in the drainage works, Piccadilly, London 1885. *J. R. micr. Soc.*, **6,** 737–63.

———. 1889. Additional Note on the Foraminifera of the London Clay exposed in the Drainage Works, Piccadilly, London, in 1885. *Ibid.*, vol. for 1889, pt. 4, 483–8.

STAESCHE, K. 1938. Die Gliederung des nordwestdeutschen Tertiärs auf Grund von Mikrofossilien. *Jb. preuss. geol. Landesanst.*, **58,** 730–45.

——— & H. HILTERMANN. 1940. Mikrofaunen aus dem Tertiär Nordwestdeutschlands. *Abh. Reichsst. Bodenf.*, 201.

STAMP, L. D. 1921. On Cycles of Sedimentation in the Eocene Strata of the Anglo-Franco-Belgian Basin. *Geol. Mag.*, **58,** 108–14, 146–57, 194–200.

STINTON, F. C. 1957. Fish Otoliths from the London Clay of Bognor Regis, Sussex. *Proc. Geol. Ass., Lond.*, **67,** 15–31.

THOMAS, H. D. & A. G. DAVIS. 1949. The Pterobranch *Rhabdopleura* in the English Eocene. *Bull. Brit. Mus.* (*nat. Hist.*) (*a*), **1,** 1–19.

TREMLETT, W. E. 1950. English Eocene and Oligocene Cardiidae. *Proc. malac. Soc. Lond.*, **28,** 115–33.

———. 1953. English Eocene and Oligocene Veneridae. *Ibid.*, **30,** 1–21, 55–71.

VENABLES, E. M. 1929. On the London Clay of the Bognor District. *Proc. Geol. Ass., Lond.*, **40,** 41–51.

WETHERELL, N. T. 1836. Observations on some of the Fossils of the London Clay, and in particular those organic remains which have recently been discovered in the tunnel for the London and Birmingham railroad. *Phil. Mag.*, (3) **9,** 462–9.

WHITE, H. J. O. 1921. A short account of the Geology of the Isle of Wight. *Mem. geol. Surv. U.K.*

———. 1925. The Geology of the country around Marlborough. *Ibid.*

WILLS, L. J. 1951. *A Palaeogeographical Atlas of the British Isles and adjacent parts of Europe.* London.

WIRTZ, D. 1939. Das Alttertiär in Schleswig-Holstein. *Neues Jb. Min. Geol-Palaeont.*, **81** (B), 215–97.

WRIGLEY, A. 1924. Faunal Divisions of the London Clay, illustrated by some exposures near London. *Proc. Geol. Ass., Lond.*, **35,** 245–59.

———. 1927. Notes on English Eocene Mollusca with descriptions of new species: the Fusinidae. *Proc. malac. Soc. Lond.*, **17,** 216–49.

———. 1928. The London Clay of Newnham (Hants). *Proc. Geol. Ass., Lond.*, **39,** 360–8.

———. 1930. Notes on English Eocene boring Mollusca, with descriptions of new species. *Ibid.*, **40,** 376–83.

———. 1930a. Notes on English Eocene Mollusca with descriptions of new species: the Muricidae. *Proc. malac. Soc. Lond.*, **19,** 91–115.

———. 1932. English Eocene species of *Sassia*, with a note on the morphology of the Cymatiidae and the Bursidae. *Ibid.*, **20,** 127–40.

———. 1934. English Eocene and Oligocene Cassididae, with notes on the nomenclature and morphology of the family. *Ibid.*, **21,** 108–30.

———. 1935. English Eocene and Oligocene Cancellariidae. *Ibid.*, **21,** 356–81.

———. 1936. An '*Aenigma*' of the London Clay. *Ibid.*, **22,** 23–6.

———. 1938. English Eocene and Oligocene Strombidae and Aporrhaidae. *Ibid.*, **23,** 61–88.

———. 1939. English Eocene *Surculites*. *Ibid.*, **23,** 277–84.

———. 1940. The faunal succession in the London Clay, illustrated in some new exposures near London. *Proc. Geol. Ass., Lond.*, **51,** 230–45.

———. 1942. English Eocene Trichotropidae. *Proc. malac. Soc. Lond.*, **25,** 100–5.

———. 1944. English Eocene Eulimidae with notes on the torsion of *Eulima* and on Charlesworth's illustrations. *Ibid.*, **26,** 47–62.

———. 1946. English Eocene and Oligocene Ampullinids. *Ibid.*, **27,** 88–104.

———. 1949. *The London Clay at Lower Swanwick, Hampshire.* Pp. 13–18 in Thomas, H. D. & A. G. Davis, 1949.

———. 1949a. English Eocene and Oligocene Naticidae. *Proc. malac. Soc. Lond.*, **28,** 10–30.

———. 1949b. The Thanet Sands. *S. East. Nat.*, **54,** 41–6.

———. 1951. Some Eocene Serpulids. *Proc. Geol. Ass., Lond.*, **62,** 177–202.

———. 1953. English Eocene *Siphonalia* and *Pseudoneptunea*. *Proc. malac. Soc. Lond.*, **30,** 121–30.

WRIGLEY, A. & A. G. DAVIS. 1924. Palaeontological Notes, pp. 146–7 in 'The Watling Street Sections through Swanscombe Hill'. *Proc. Geol. Ass., Lond.*, **35,** 142–9.

———. 1937. The Occurrence of *Nummulites planulatus* in England, with a revised correlation of the strata containing it. *Ibid.*, **48,** 203–28.

DISCUSSION

DR. J. F. HAYWARD said that he had derived much pleasure from hearing the paper. He wondered whether the 'typical' blue London Clay of text-books existed except in a limited area. In his experience the London Clay was rarely blue and varied considerably in its lithology.

Besides the localities mentioned in the paper he, Dr. Hayward, could quote two occurrences of *Balanocrinus* in western Essex. He would be pleased to supply Mr. Elliott with details.

DR. R. S. COLLINS asked, what were the speaker's views on the value of particular species as palaeoclimatic indices.

MR. E. E. S. BROWN enquired whether the Authors had undertaken heavy mineral studies to determine the provenance of the bulk of the London Clay sediments; he also spoke on the origin of the pebble-beds in the London Clay.

DR. W. S. PITCHER asked for certain information on the age of the Cuise sands. He congratulated the Authors on their valuable synthesis and agreed that the nomenclature of the Lower Tertiary strata was unsatisfactory. Thus 'Landenian' and 'Ypresian' were not being used properly as stage-names for they applied to sedimentary cycles, the boundaries of which were necessarily diachronous.

THE PRESIDENT, MR. C. W. WRIGHT, spoke of the proliferation of stage-names, and welcomed simplification on the lines proposed.

MR. ELLIOTT, in reply, thanked the meeting for their reception of the paper, and regretted that the senior Author, Mr. A. G. Davis, had not lived to be present. In reply to Dr. Hayward, he agreed that London Clay included various types of sediment, but felt that the stiff blue clay, coursed with septaria and weathering brown, of the London area, Essex and north Kent, might be regarded as typical, i.e. occurring in the type area, in spite of occasional anomalies like that described by Whitaker at Highgate (1889, *Geology of London*, **1,** 257). He thanked Dr. Hayward for the Essex records of *Balanocrinus*.

To Dr. Collins he said that he regarded species of land-plants and reef-forming corals as the only wholly reliable palaeoclimatic indices.

In reply to Mr. Brown, he regretted that neither he nor the late Mr. Davis had studied the heavy minerals of the London Clay: he agreed that much of the fine sediment might possibly have come from the Gault, and hoped that work he believed now in progress might clarify this point.

He referred Dr. Pitcher to the work of Abrard & Soyer (1942). After paying acknowledgment to the Acting Director of the Botanic Gardens, Singapore, to whom he was indebted for the photographs of modern *Nipa* shown as lantern slides, he thanked the President and others for their interest in, and approval of, the proposed simplification of stage-names.

Mr. Elliott informed the meeting that the paper as written was jointly prepared by himself and the late A. G. Davis. More recently, Miss M. E. J. Chandler, *in litt.*, considers that in view of recent studies of the pre-London Clay Tertiary floras, no longer regarded as temperate, the London Clay flora may not have changed sufficiently to yield palynological zones within the formation. She also stresses the size of the fruit-floras now known from Bognor and Herne Bay, though Sheppey is still much the largest.

The Distribution of Dolerite Boulders in the Glaciation of N.E. Derbyshire

by A. C. DALTON

Received 30 October 1954

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ABSTRACT: The distribution of erratics on the northern portion of the limestone district of Derbyshire is considered. These travelled stones include a few Lake District and Scottish rocks, but by far the most abundant are basalts and dolerites ('Toadstones') of local origin. The occurrences of the latter boulders have been plotted on maps when they appear as streams trending in a general direction from west to east. From this, the conclusion is drawn that they were transported by a glacier passing through the Dove Holes gap and spreading fanwise to the east of that gap over the limestone area.

1. INTRODUCTION

WHILE the Derbyshire Dome, in the past, was commonly thought of as a 'Driftless' or relatively driftless area, in that 'Till' or 'Drift' sediments of any kind are most rare, it does not necessarily mean that it was unglaciated. Indeed, erratics are known everywhere, even on the highest ground, and from their distribution much can be inferred. Even so, evidence of this kind is not always easy to interpret, as Jowett & Charlesworth found (1929, p. 315). They commented: 'How did these boulders reach their present position? It would appear that there are two possibilities:

'1. The rafting of the boulders in an extra-glacial lake submerging the higher part of the valley, and held up by an ice-dam, situated about the confluence of the Derwent and the Wye, and forming the eastern flank of the ice, burying the Derbyshire Dome on the west and south-west.

'2. The direct transport by an ice-sheet which had surmounted the surrounding hills, the lowest cols of which are nowhere less than 1600′ [*sic*] above sea level.

'In the present state of ignorance and uncertainty as to the extent and direction of ice-movements during the period of the Older Drift, more particularly in the area west and north-west of Sheffield, it is difficult, indeed impossible, to decide between the two explanations, both of which seem hard to believe. We feel that the view of direct transport by an ice-sheet offers the better solution, although for some time we accepted the other. Definite proof, however, can only be brought forward by investigations outside the immediate area under discussion. In changing our opinion on this question we were influenced by the shallowness and narrowness, from the point of view of an overflowing mass of ice, of the col at Dove Holes, and the seeming impossibility of overriding the whole of the Dome by an ice-mass through so restricted an opening.'

2. REASONS FOR THE RESEARCH

During the search for glacial erratics in the Eyam area, numerous boulders of toadstone (as the local Dolerite is called) were frequently seen, but, as these were considered of local origin, they were not thought of significant importance. Nevertheless, the frequency of these boulders of very varying size and shape often used in the construction of the 'dry' walls for which this part of Derbyshire is noted, suggested that, by mapping their position, light might be thrown on the ice-stream which brought them. Associated with these boulders are numerous Lake District erratics, also found in the walls (Table I). It was soon apparent that in the Eyam and Stoney Middleton areas there was a very considerable concentration of toadstone. Since this rock is known to outcrop west of these areas, it seemed probable that they had originated there, and since the passage of ice from the west, probably through the Dove Holes gap, had been previously accepted (Dalton, 1945), the same means of transport for these boulders was probable. To the use of boulders found in walls, some may demur, but it is of interest to note that Dale (1900) admits that many of her records in the Buxton area were obtained under similar conditions. Fortunately there is still much evidence today of boulders too large for ordinary handling, and which have been dragged to the pasture edge, and in one case, a boulder near Farnley Lane approximately ten hundredweight, and situated at 1000 O.D., was being broken up to repair the adjacent wall. The boulders are of varying size, and many have rounded and sub-angular edges, at first suggesting water carriage, though more probably due merely to the characteristic spheroidal weathering of this rock.

3. AREA COVERED BY THIS RESEARCH

The western side of the area covered by this paper is from Dove Holes to Buxton, whilst the River Derwent forms the eastern boundary; on the south, the River Wye forms a partial boundary. The country concerned is hilly, but not mountainous, in fact Derbyshire has been described as a dissected peneplain, consequently the valleys are more in the nature of ravines rather than broad open valleys. Their direction is of interest as they may have influenced the direction of the ice-stream. The main valleys, passing from the east to west, are Stoney Middleton Dale and Coombes Dale in an eastward direction, Ravens Dale and Tideswell Dale north to south direction, whilst the remaining ones, Monk's Dale, Woo Dale, Great Rocks Dale and Cunning Dale, run south-east. These latter are all between Miller's Dale and Buxton. The bed-rock is chiefly Carboniferous Limestone, though the covering shales and grit series are met on the western, and to a lesser extent on the northern boundary.

From Tideswell Dale to Buxton there are several exposures of Dolerite in sills, mapped by Bemrose (1907), as Olivine Dolerite. How much these various beds were subjected to glacial erosion must naturally have been influenced by their surface exposure. One important source of Dolerite boulders seems to have been the sill at Water Swallows in the Fairfield parish of Buxton. This exposure, the largest in the area, covers some 50 acres and is partly covered by Drift with erratics. Another exposure is at Knot Low, 950 feet, in Miller's Dale. This bed must have suffered considerable erosion from its exposed position between Miller's Dale and Monk's Dale. Tideswell Dale comes next, but owes its exposure to the cutting of the Dale which, it will be remembered, is in a north to south direction and would therefore be transverse to the direction of movement of ice passing from the west.

4. THE PROBLEM

Initially, before the western ice crossed the Dove Holes col, no doubt considerable local ice formation must have taken place, which would prepare the Dolerite for ice transportation. If this had been sufficient to cause some loose material to be transported, then surely the main valleys (Fig. 1) would have been the directing channels. Of these the Wye would have the major influence, running to the south-east, and only later would there be sufficient pressure to carry local material in a north-easterly direction, over the 1000 O.D. contour which surrounds Eyam. Assuming that there was a local ice-mass of minor importance filling the valleys, this would form a floor for the passage of a much greater and more powerful western ice-stream subsequently crossing the Dove Holes col, and bringing the Lake District and Scottish erratics. On that assumption, these erratics, perhaps chiefly surface borne, would be dropped when the ice became stagnant and melted, and this accounts for their distribution over Derbyshire without other apparent glacial evidence. A somewhat similar condition is noted by Garwood (1899) in Spitzbergen where, as he says, 'We

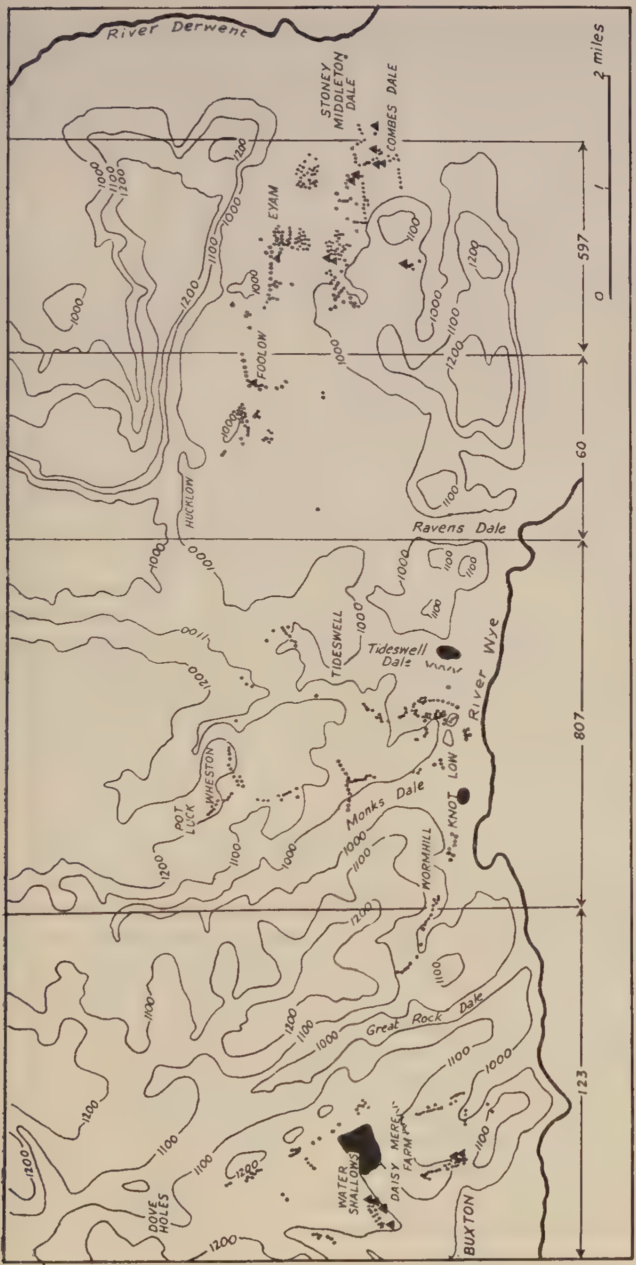

Fig. 1. Diagram to show the southern pattern of dolerite boulders between Buxton and Stoney Middleton. Dolerite boulders are indicated by dots and the outcrops shown in black. Lake District erratics are represented by triangles. Zig-zag lines indicate 'contact zone' in which walls are made of dolerite. Contour lines below 1000 feet are not shown

still have undoubtedly the effects of an ice-sheet with its valley-bound ground ice and freely moving surface layers, with the result that the latter travel in an independent direction, frequently at right angles to the former'.

Nearer home, there is the comparable case high up the Eden Valley (Trotter, 1929).

5. THE DISTRIBUTION DIAGRAMS

All boulders were plotted on the six-inch sheets of the Ordnance Survey except were the numbers were far too many for the space, then a line was made with the number recorded (Table II). Later, tracings were made from the six-inch maps which were reduced to the two-and-a-half-inch scale (Figs. 1 and 2).

As a rule all boulders were chipped for identification; the dark blue crystalline type of Dolerite was taken as standard, though variations were seen on the fractured surfaces. It is unfortunate that this type of rock does not lend itself for easy identification as to a definite exposure. Although the whole of the country between Stoney Middleton and Dove Holes, a distance of ten miles, has not been examined in detail, sufficient ground has been covered to reveal a pattern in the distribution of these boulders, namely, a wide, shallow 'V' open to the north, with the apex in the region of Miller's Dale. This suggests a main stream from Dove Holes in a south-easterly direction, which was probably diverted at Priest Cliff, north of Miller's Dale, so that one arm passed north-east to Eyam and Stoney Middleton. It is of interest to note, though this is not brought out in the diagram, that the greatest concentration is found on the 900-foot contour. The six-inch sheets reveal this more clearly. Between the forks of the V, only a thin and widely scattered line of boulders is recorded, and these tend to follow the 1000-foot contour.

After passing Foolow in a westerly direction, outcrops of Dolerite occur, and naturally there is a rapid increase of boulders. When these occur near an outcrop they are not counted; these I will call 'Contact Zones', which are marked on the map by a zig-zag line. The walls in these areas are almost entirely built with boulders, as at Tideswell Dale, and Daisy Mere Farm at Water Swallows, etc. Water Swallows, being in the direct line of the ice-stream from Dove Holes, must have suffered considerable erosion, but there is to the west of this exposure a strong line of boulders (123) leading up to the entrance of Dove Holes village, approximately two miles. Miss Dale noted this, and suggested an east to west ice-stream. This is very doubtful, the Peak Dale area being more likely, though there is always the possibility that some may have a still more western origin, being brought through the col at Dove Holes.

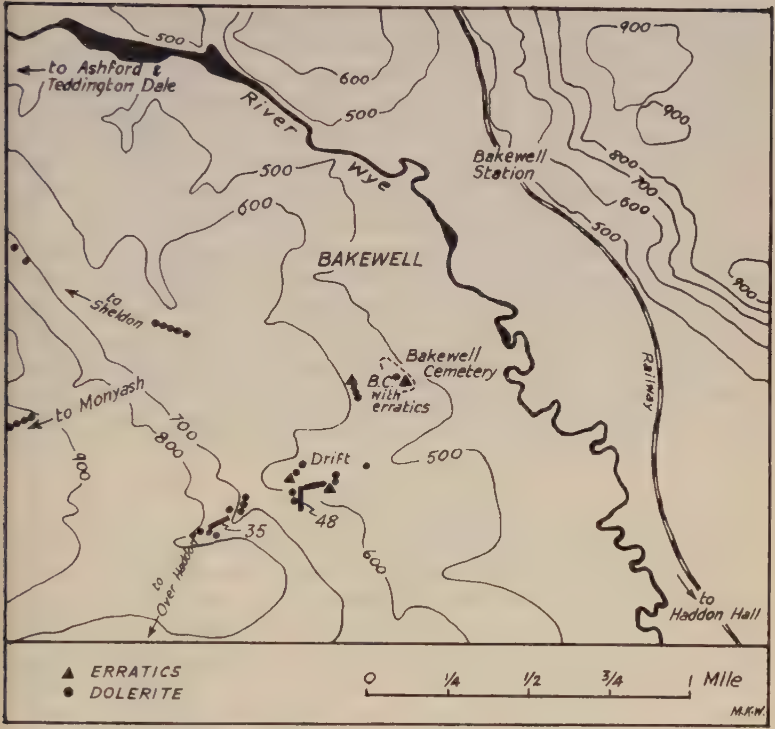

Fig. 2. Diagram to show the scatter of dolerite erratics around Bakewell

6. SUGGESTED INTERPRETATION

The scatter diagram leads to the question of the movement of an ice-sheet, for it is as such we must consider it. As the country became intensely glaciated, and glaciers began to move in a southerly direction, it would appear that any local glaciation of Derbyshire was not of sufficient intensity to travel far, and was soon held up in the south of the County by the confluence of the great western and eastern ice-stream, thus the Derbyshire ice would become stagnant, though the intensity of arctic conditions may have been sufficient to prepare local material for transport, in the immediate valleys. What height this stagnant ice reached is unknown but eventually the pressure from the west was sufficient to mount the barrier of the Pennine ridge and overflow where cols were suitable, as at that maximum which brought marine shells to Macclesfield (approx. 1200 feet O.D.).

This ice-stream bore the erratics from the Lake District and Scotland, perhaps as a surface-borne stream of boulders. It was relatively clean as witnessed by the absence of typical 'Till' or boulder clay (Geikie's 'bottom moraine'), though there are beds of material that might be considered as approaching the nature of 'Till', due, perhaps, to the material not having travelled sufficiently far, or due to lack of pressure and movement. This lack of clay cover may account for the rarity of striations, there being only those seen on the limestone in Stoney Middleton Dale (Dalton, 1945). Further, if the Lake District erratics were surface-borne by the ice passing the Pennine cols, and subsequently dropped over Derbyshire as the stagnant ice melted, the suggested lakes would then be unnecessary. Nevertheless, though the scatter diagram does suggest that the ice-stream passing Dove Holes in a south-easterly direction was split into two or three main streams, one of which took a north-east direction to Eyam and Stoney Middleton, it does not offer any explanation as to why so many boulders were finally deposited in that area, beyond the suggestion that the Derwent Valley was already full of ice, which may have been the chief route followed by any ice from the Peak area.

7. CONCLUSIONS

Though hill-creep or solifluxion may subsequently have played a part in the distribution of some boulders, this cannot account for those in the Eyam area, so that the picture suggested to my mind is an area being covered by a local field of stagnant ice, possibly up to 900 or 1000 feet O.D. that was overrun by an ice-stream from the west which passed through the Dove Holes gap, and spread out fanwise, suggestive of the Malaspina Glaciers. The high ground around Priest Cliff caused one stream to take a north-easterly direction towards Eyam and Stoney Middleton area, whilst one passed via Miller's Dale, Monsal Dale and Taddington Dale to the Bakewell area (Fig. 3), and another in a southerly direction as suggested by Bemrose. It is of interest to note that Bemrose (1907, p. 252) says he and Deeley were able to trace the southward passage of the ice by the Dolerite blocks from Calton Hill (1300 feet O.D.), which is just south of the area of this research. What height this western ice-stream ultimately reached is not yet proven, but between 1300 and 1400 feet seems probable. Conditions west of the gap which caused this overflow would be of interest, and we come to the conclusion of Jowett & Charlesworth that 'Evidence must be brought from the outside of the area concerned'.

ACKNOWLEDGMENTS

The author would like to record his gratitude to W. H. Wilcockson, M.A., F.G.S., of Sheffield University, for giving him so much of his valuable time in advice on field problems, and for his encouragement, to Norwood Greaves for his patience in drawing the maps, and also to R. G. Carruthers for much friendly criticism.

TABLE I: **Lake District and Scottish erratics found between Bakewell and Buxton:**

Porphyritic plagioclase granite
Microgranite
Basalt
Ennerdale Granophyre
Basic Tuff
Ash with garnets
Eskdale Granite
Scottish white Granites
Greywacke
Old Red Sandstone
Andesitic Ash
Olivine Basalt
Andesitic Lava
Rhyolite
Biotite Granite
Borrowdale Lava
Pyroxene Andesite
Quartz Porphyry

TABLE II: **The number of Dolerite Boulders recorded on the six-inch Ordnance Survey map are as follows:**

Eyam and Stoney Middleton area	597
Foolow	60
Tideswell	12
Tideswell–Monksdale	628
Wormhill	170
Green Fairfield–Dove Holes	123
TOTAL	1590

REFERENCES

BEMROSE, A. 1907. The Toadstones of Derbyshire. *Quart. J. geol. Soc. Lond.*, **63**, 278.

DALE, E. 1900. *The Scenery and Geology of Derbyshire*, p. 122.

DALTON, A. C. 1945. Notes on some glacial features of North-East Derbyshire. *Proc. Geol. Ass., Lond.*, **56**, 30.

GARWOOD, E. J. 1899. Additional Notes on the Glacial Phenomena of Spitzbergen. *Quart. J. geol. Soc. Lond.*, **55**, 68.

JOWETT, A. & J. K. CHARLESWORTH. 1929. The Glacial Geology of the Derbyshire Dome and the Western Slopes of the Southern Pennines. *Ibid.*, **85**, 307.

TROTTER, F. M. 1929. The Glaciation of Eastern Eden-side, The Alston Block and the Carlisle plain. *Ibid.*, **85**, 549.

Slump-Structures in the Ludlovian Rocks of North Herefordshire

by B. J. WILLIAMS and J. E. PRENTICE

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ABSTRACT: Small-scale folding in the *Monograptus tumescens* Zone of the Ludlovian is ascribed to movement at nearly the same time as the sedimentation, and is shown to be concordant with the trend of larger 'slump' structures; the whole pattern indicating a general movement of the beds towards the north and west. The minute folds of the bedding-plane are called 'crinkle-marks'. It is concluded that the strata were still unconsolidated during their movement, but that no extensive translation of material is involved. The problem of beds showing two or more directions of crinkling is discussed.

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1. INTRODUCTION

THE STRUCTURES here described were discovered during an investigation of the Silurian rocks of an area south-west of Ludlow, bounded by the villages of Aston, Richard's Castle, Leinthall Earls and Leinthall Starkes (see Fig. 1). The authors' attention was first drawn to the markings by Dr. J. D. Lawson. The junior author (B. J. W.) carried out most of the field-work and the investigation of sectioned specimens; the senior author (J. E. P.) accompanied him in the field, suggested some of the lines of investigation, and generally supervised the progress of the work. The authors are jointly responsible for the final form of the manuscript.

'Slump'-structures have been described from the Silurian rocks of Wales by several authors; some of the structures described are comparable with those of North Herefordshire. Thus minute crumpling or corrugation of bedding-planes in Lower Ludlovian disturbed strata was described by Jones (1937, p. 245), and in the same year Straw recorded corrugation of bedding surfaces with corresponding internal puckering of the laminae in Lower Ludlovian rocks in the Builth district (1937, p. 441). Similar phenomena have been recorded by Earp (1938, p. 141), who noted the fact that small-scale puckering is often found in otherwise normal rocks within the contorted beds of the Kerry district; and in a description of the Colwyn

Bay region, Jones (1939, p. 341) included highly distorted bedding and crinkly surfaces among the distinguishing features of slumped mudstones. It seems, therefore, that these features are widespread in slumped sediments, and that they merit closer investigation and more detailed description than has been hitherto accorded them.

In the region under description, slumped beds are virtually confined to the *Monograptus tumescens* Zone of the Lower Ludlovian. The zone is composed of light grey muddy and limy siltstones, with conspicuous flaggy calcareous bands up to six inches thick. The rocks are mostly laminated, the laminations consisting of dark-grey fine-grained bands up to two mm. thick, alternating with light-grey coarser calcareous and silty bands up to eight mm. thick. The latter bands usually make up about eighty per cent of the thickness of the rock. The small-scale structures are visible as a result of the contortions of the laminae.

Slumping does not appear to have begun until the deposition of the *M. tumescens* Zone, since the underlying mudstones (Zone of *M. nilssoni* and *M. scanicus*) are apparently devoid of slump structures. These fine-grained rocks are, however, not usually laminated, readily weathered, and are seldom well-exposed. The stratigraphic diagram (Fig. 2) shows that the *M. tumescens* flags thicken apparently towards the south-west; this thickening is accompanied by a progressive upward extension of the slumped beds to higher stratigraphic levels. Thus at exposure **8**[1] the whole of the zone is affected by the disturbance, whilst at section **9** ill-defined contortions extend upwards into the transition beds below the Aymestry Limestone. Furthermore, the complexity of the 'slump'-structures increases towards the south-west; and over-folding is best developed in the upper parts of exposures **7** and **8**. It seems reasonable to suppose that the thickening of the zone is a direct consequence of the greater intensity and possibly longer duration of the slump movements in the south-west than in the north-east.

2. DESCRIPTION OF THE STRUCTURES

The 'slump'-structures of the *M. tumescens* flags assume two main forms. The more obvious are folds of fairly large dimension, which vary from complex recumbent folds to gentle undulations of up to six feet in amplitude. No 'balling-up' or separation of masses of strata has been observed; otherwise these folds are quite comparable with 'slump'-structures described from other regions. The second form shows itself as a series of sub-parallel corrugations of the bedding-plane surface; and sectioning the rocks shows that these corrugations are a direct reflection of a crumpling of the internal lamination. The appearance of the bedding

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[1] Bold figures in text refer to localities shown in Figs. 1 and 2.

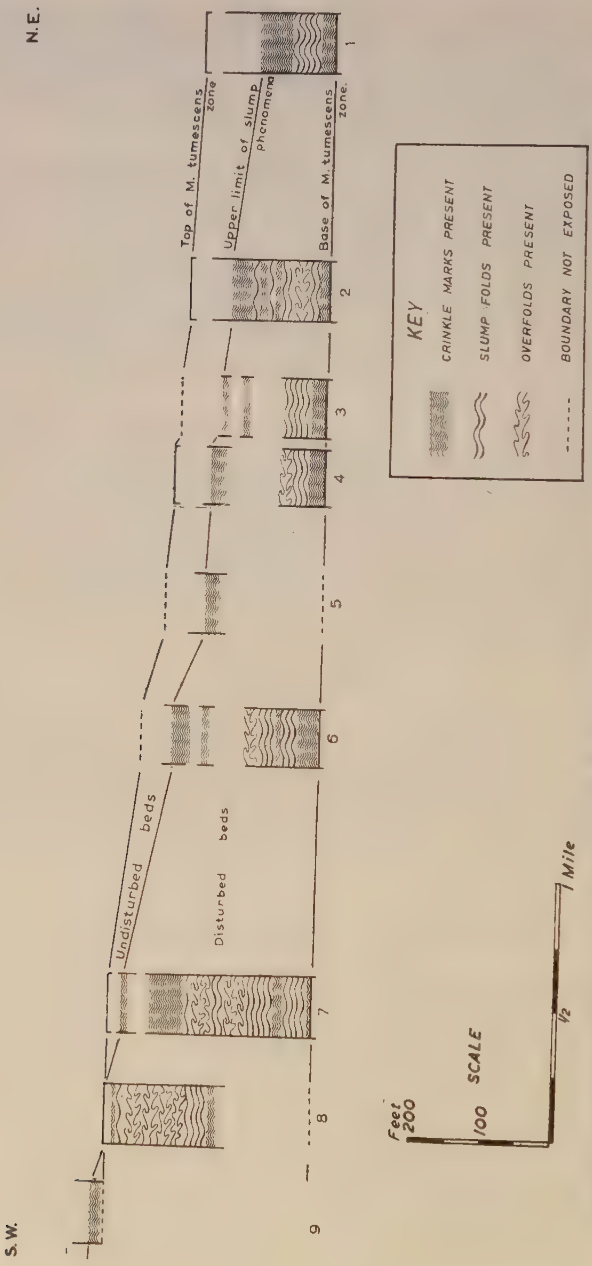


Fig. 2. Diagrammatic section along the outcrop of the *M. tumescens* flags, showing vertical extent of 'slumping' phenomena. (Figures at foot of sections refer to localities, see Fig. 1 and text)

surface is so characteristic that the need is felt for a special name; it is here proposed to call the surface markings ‘crinkle marks’.

The crinkle marks (Plate 6) are a series of sub-parallel ridges, usually asymmetric in form, which rise to a height of up to three mm. above their intervening troughs. The distance from crest to crest varies from one mm. upwards. The height of an individual ridge varies considerably along its length. The appearance of these structures on a bedding-plane is that of a somewhat irregular lineation superficially similar to the fractured surface frequently seen in highly cleaved strata. On some bedding surfaces there are two or three sets of crinkle marks, so that the surface is broken up into a reticulate pattern of pits and ridges.

The internal structure of the crinkle marks was studied by serial sectioning in a plane normal to the bedding and at right angles to the folds. Intervals of 0.02 and 0.5 mm. were used, according to the amplitude of the folds, and the structures were clearly revealed by etching the ground surface with ten per cent hydrochloric acid. *Camera lucida* drawings of each section were made, and an enlarged model constructed in sheets of cardboard, based on a well-defined bedding surface. The form of the folds (Fig. 3) is nearly always asymmetric, generally overturned in the same direction. They vary in intensity from simple asymmetrical anticlines to recumbent and nappe-like forms. Digitations, forward and rearward projections of ‘Alpine’ type are common and the lower limb of the fold may pass into a minute overthrust. The argillaceous laminae are more intensely contorted than the silty bands, which appear to have acted as relatively competent beds. Where the thicker silty bands are particularly coarse-grained and calcareous, the fold-form is bulbous, and the asymmetry indistinct. In beds where lamination is not marked the contortions are difficult to follow.

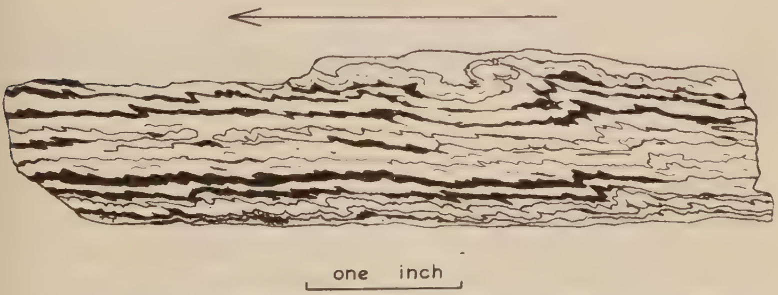


Fig. 3. Diagram to show the form of the minor folds; direction of sediment movement shown by the arrow. *M. tumescens* flags, Elton Lane (Locality 2). Drawn from a photograph

Where two or more sets of crinkles have affected the rock the internal structure is very complex; and when serial sections are cut normal to the trend of one set of folds, their crests and troughs may be seen to rise and fall along that trend. In each set of folds the structure is asymmetrical with a constant direction of overturning. Plate 6 shows a specimen in which two sets of folds intersect at nearly 90°, with a great disparity in amplitude between the two sets. The broad folds resolve themselves on sectioning into anticlinoria and synclinoria, in which the constituent anticlines are uniformly asymmetrical.

Graptolites which are lying on a bedding surface tend, if aligned along the trend of the crinkles, to occur in the troughs of the folds; those which lie across the crinkle crests are broken by them. When graptolites lie at an angle to the bedding they are usually broken by the folds and sometimes cut by the minute overthrusts. In some finely laminated and very silty rocks which show only gentle crinkling, broken graptolites are associated with a local intensification of the crinkling, with greater disturbance on one side of the graptolite than on the other (see Fig. 4).

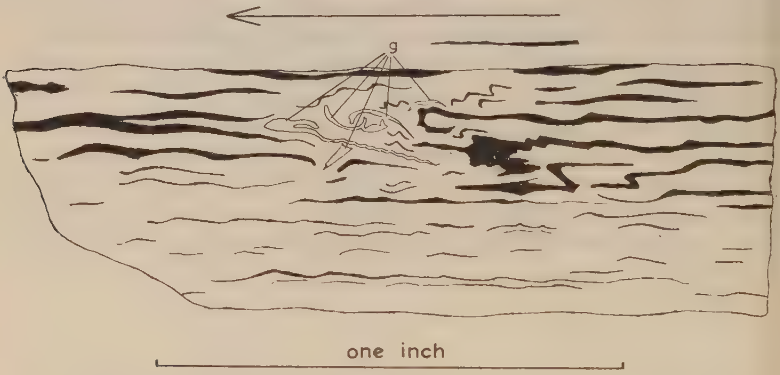
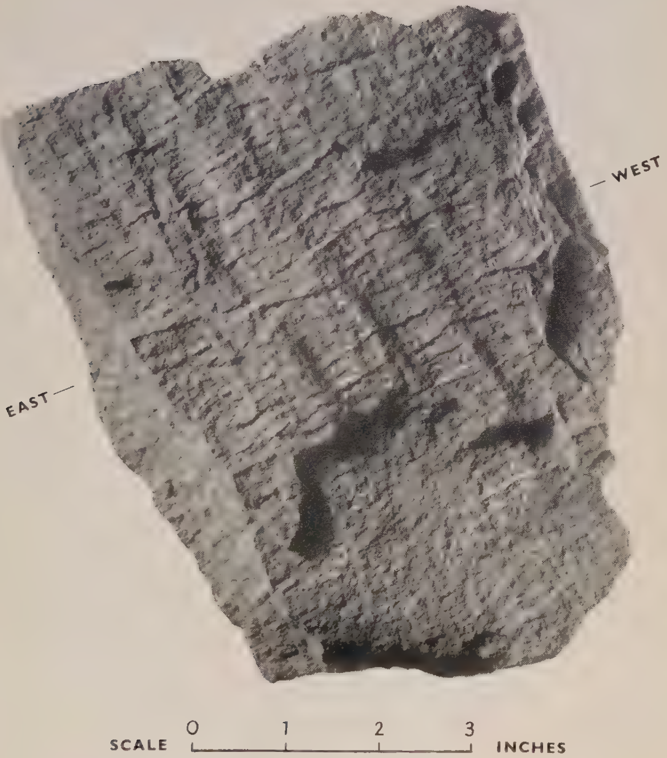


Fig. 4. Diagram showing piling up of folds against fragments of graptolites (g). The arrow shows direction of sediment movement. *M. tumescens* flags (Locality **8**). Drawn from a photograph

The crinkle marks are found associated with both highly overfolded and gently undulating slump-folds; they are also found in strata where large-scale folding is not apparent. In fact, it is in the latter environment that they show the greatest regularity. In the overfolds they are less regular and the direction of overturn of the crinkles is not constant, whilst distortion is at its maximum at the axis of the overfold. Rocks with two directions of crinkling occur in both overfolded and flat-lying strata.



Crinkle marks, *M. tumescens* flags, Elton Lane (Locality **2**).

Upper surface of a bed showing two directions of crinkling intersecting at nearly ninety degrees

3. INTERPRETATION

The word 'slump', as interpreted by the authors, implies the flowage of a mass of sediment, shortly after its deposition, down a slope. It is necessary to distinguish such structures from those produced by tectonic activity and those produced by turbidity current deposition. The clearest indication of true slumping is found when the upper surface of a slump sheet is eroded before deposition of the next stratum (e.g. Kuenen, 1948, fig. 8). In this area, the contacts between 'slumped' and undisturbed strata are rarely seen. In section **1** it is possible to fix the line where crinkling ceases, but here the crinkling is small and if any erosion of the crinkled beds did occur it would be very difficult to detect. In the south-west of the area (section **8**) truncation of the top of some of the overfolds does occur, but within the 'slumped' sequence. Although there is no positive evidence for movement penecontemporaneous with the deposition the structures are closely comparable with those of indubitable 'slumped' origin elsewhere.

The 'slump'-structures simulate the form of tectonic drag-folds in following the strike of the regional anticlinal axis, and being overturned towards it. However, it is known that the Ludlow anticline is a gentle arch whose dips do not exceed 18° on the south side. The amount of slip x, generated between two bedding planes y units apart by movement through θ degrees in a competent fold is given by the formula $x = y \tan \theta$. Thus the top of the 250 feet of the *M. tumescens* flags can be shown to have moved eighty feet nearer to the anticlinal axis than did the base. This amount of slip could only cause a lamina to be shortened by less than one third of its length. It is obvious (Fig. 3) that in fact much greater shortening is involved.

The larger overfolds may be shown in the south-west of the area (see above) to be penecontemporaneous with the sedimentation and the crinkling direction accords with these. The fact that the small crinkles are sometimes 'underfolded' on the lower limbs of these overfolds shows that the crinkles have an earlier origin and are not the result of drag developed in the formation of the overfold. The disorganisation of the crinkling at the overfold axes shows that the strata were in an unconsolidated state throughout. It is noteworthy that north-easterly and north-westerly joints transect the whole slump series; if these were formed, as is theoretically possible, by the same compression that folded the Ludlow anticline, then clearly the crinkling preceded the tectonic folding.

The internal structures of the crinkled beds also suggest a contemporaneous rather than a tectonic origin. There are no slickensides or listric surfaces, no brecciation, and no tension gashes either open or quartz filled (contrast Cope, 1946). The behaviour of the crinkling in relation to the graptolites (Fig. 4) also strongly suggests movement whilst the sediment was still soft. The authors thus claim that the wrinkling was completed before consolidation, and that the structures are non-tectonic in origin.

Nor will these structures bear comparison with those in rocks formed by turbidity currents; the convolute bedding of the normal greywacke sequence (Ten Haaf, 1956) dies out upwards and downwards, and overturning is neither frequent nor constant in direction.

The rocks seem to have been poorly consolidated during the formation of the 'slump'-structures. They were mobile enough to allow some graptolites to be oriented along the troughs of the folds, but sufficiently consolidated to fracture those which lay opposed to the movement. Since crinkles may be seen to be congruent with one another through more than an inch of rock, it is clear that individual laminae did not move independently (see Fig. 3). The presence of local unconformity within the overfolded strata, and of undisturbed beds within the disturbed sequence (seen in sections **1** and **2**), suggests that movement was in the form of a series of slump-sheets, rather than a mass-movement of the whole sequence at one time. The general low intensity of slump-folding in this region suggests that actual translation of material was slight, and that these structures represent relatively minor adjustments to the position of the sediment on a slope.

By analogy with the drag-folds produced by diastrophic movement, and by comparison with the artificially produced folds described by Rettger (1935, figs. 3 and 4), it is believed that the movement of the sediment was at right angles to the trend of the fold axes. It is difficult to interpret those crinkles which lie in two or more directions. They may have been formed by movement down local depressions in the sea-floor, so that the sediment was deflected from its original direction. Usually one set of crinkles is dominant, and this may be taken to indicate the main direction of slope.

4. CONCLUSIONS

The rocks of the *M. tumescens* Zone have developed internal contortions and slump-folds as a result of relatively small-scale adjustments of the sedimentary cover to its sloping bed. The orientation of the structures implies a slope varying from northward to westward and intensity and duration of movements increase westward. It is generally believed that this area is a zone of transition between the 'shelf'-facies on the east and the 'basin'-facies on the west (Lawson, *et al*, 1956). The results here presented show close accord with this conception.

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REFERENCES

Cope, F. W. 1946. Intraformational Contorted Rocks in the Upper Carboniferous of the Southern Pennines. *Quart. J. geol. Soc. Lond.*, **101,** 139–76.

Earp, J. R. 1938. The Higher Silurian Rocks of the Kerry District, Montgomeryshire. *Ibid.*, **94,** 125–60.

Jones, O. T. 1937. On the Sliding or Slumping of Submarine Sediments in Denbighshire, North Wales, during the Ludlow period. *Ibid.*, **93,** 241–83.

———. 1939. The Geology of the Colwyn Bay District; a study of submarine slumping during the Salopian period. *Ibid.*, **95,** 335–82.

Kuenen, P. H. 1948. Slumping in the Carboniferous Rocks of Pembrokeshire. *Ibid.*, **104,** 365–85.

Lawson, J. D. *et al.* 1956. The Ludlovian Rocks of the Welsh Borderland. *Advanc. Sci., Lond.*, **13,** 563–70.

Rettger, R. E. 1935. Experiments in Soft-Rock Deformation. *Bull. Amer. Ass. Petrol. Geol.*, **19,** 271–92.

Straw, S. H. 1937. The Higher Ludlovian Rocks of the Builth District. *Quart. J. geol. Soc. Lond.*, **103,** 406–56.

Ten Haaf, F. 1956. Significance of Convolute Lamination. *Geol. en Mijnb.*, **18,** 188–94.

The Pleistocene Deposits of Penfold's Pit, Slindon, Sussex, and their Chronology

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ABSTRACT: The deposits from sections at Penfold's Pit, Slindon, are described both macro- and micromorphologically. Fossil soil horizons are identified and deductions made as to their primary origin. Finally the relative and absolute chronology of the Pleistocene deposits is inferred.

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1. INTRODUCTION

OUTSIDE RECENT isostatically affected areas, such as Fennoscandia or the coast of North America, evidence has accumulated for fluctuations of the sea-level during the Pleistocene that are independent of the movements of the land. Phases of high sea-level are evidenced by ancient shore-lines, often called raised beaches. All along the south coast of Britain ancient beach deposits are found which can be referred to the Tyrrhenian level of thirty-two metres, the Main Monastirian of eighteen metres, the Late Monastirian of seven and a half metres and the Epimonastirian of three metres. Those between Portsmouth and Brighton, especially 'the 100 foot' beach of Tyrrhenian or Great Interglacial age, containing numerous palaeolithic implements and sites near Chichester, including Slindon, have been described by Reid (1887 and 1892), Prestwich (1892), Palmer & Cooke (1923), Fowler (1932), Calkin (1934), Oakley & Curwen (1937), Zeuner (1945 and 1952) and Pyddoke (1950) amongst others.

2. SUMMARY OF PREVIOUS RESEARCH

Summarising the evidence so far presented, it would seem that in this area there is a continuous sheet of sand and gravel at eighty to ninety feet O.D. (Aldingbourne beach), though in pits near Waterbeach and Slindon marine deposits reach or exceed 130 feet O.D. The marine sand at Waterbeach contains a temperate interglacial fauna (Reid, 1892 and 1903; Palmer & Cooke, 1923), whilst both there and at Slindon it is overlain by a reddish, unstratified, clayey gravel known as 'coombe rock' or by the more vague term 'head'. This material has generally been interpreted as a solifluction deposit and was first described as such by Reid (1887), who regarded it as debris from coombes formed under tundra conditions.[1] Doubt as to its origin, however, has been expressed since, although this sheet of head is likely to be the product of cold conditions, it is doubtful whether solifluction was active during any part of the interglacial when the sea-level was high and the climate temperate.

Oakley & Curwen (1937) have noted that in Marshall's Pit at Slindon the sand is to some extent interbedded with the lower part of the gravel. This supports the 'pseudo-solifluction' hypothesis of Zeuner (1952), who considers that during the final phase of transgression the sea reworked some of the head which may have formed a cliff and which collapsed or otherwise became spread over a part of the abandoned beach. Some traces of fossil cliffs in this area have been mentioned by Reid (1892), but other workers have been unable to find any. This is not surprising since periglacial conditions must have occurred more than once since the formation of the fossil beach and most of the evidence of the cliff line has probably been obliterated by erosion.

3. AIM OF INVESTIGATION

The only good exposure of the beach deposits in the Slindon area today is in Penfold's Pit. In the centre of the pit the marine sands contain large rounded pebbles often noded by wave action, but the face at present being worked lies to the north and over seven feet of head is normally exposed. This material appears to thin up-slope to the north and it seems probable that the section now visible lies well beyond the fossil cliff line. If so, the head would rest directly on the old land surface and would not represent collapsed cliff material equivalent in time to the water-laid deposits on the southern side of the pit. Thus, it was thought that the apparently undifferentiated mass of head might contain horizons of fossil soil material which had become incorporated by colluvial activity. These might be identified by micromorphological techniques (Dalrymple, 1955) and their recognition allow certain climatological deductions to be made and so help to establish the relative chronology of the site.

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[1] Reid (1887) was also the first author to equate the brickearths of southern England having a 'cold arctic' fauna with the loess periods in central Europe.

4. MACROMORPHOLOGICAL AND MICROMORPHOLOGICAL DESCRIPTION OF SECTIONS

The section visible in the northern face at Penfold's Pit in 1954 (Fig. 1) comprises a six-inch overburden underlain by ten feet six inches of deep-red clay mixed with chalk rubble. This head material appears to be uniform in composition and completely unstratified apart from brodel phenomena (Zeuner, 1945) in the uppermost two feet and an orange-brown layer some six inches from the base. The base of the section was obscured by talus and the total thickness of head is unknown. The brodel pockets, semi-circular in cross-section, contain no red clay and are composed of white chalk rubble mixed with a small quantity of silt-loam, light brown in colour. The orange-brown layer contains a higher percentage of clay and is characterised by numerous manganese spots and concretions.

The micromorphological study of these deposits showed that in thin section the head contains small pieces of flint and chalk which are completely surrounded and held in a finely divided ground-mass. This is light yellow in colour and the occurrence of flow-structures shows that the ground-mass is still highly mobile. Dispersed within it, however, are areas containing deep-red flecks and precipitates of iron which have resulted from concentration and dehydration *in situ*. This fabric is of the rotlehm[1] type which today is found in the B horizons of certain subtropical and tropical soils.

In contrast the orange-brown horizon has a ground-mass consisting of irregularly shaped mineral grains which are connected and held by deep-brown flocculated aggregates. There are numerous cavities within the fabric which for the most part are empty, but a number of thin cracks are lined with deep-yellow colloidal material. Thus, the orange-brown horizon has a braunerde fabric with minor *sol lessivé* features and is similar to fabrics observed from the B horizons of certain mull soils of the northern temperate forests.

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[1] Fabric nomenclature is that of Kubiena (1948 and 1953). 'Lehm' fabrics consist of a ground-mass of colloidal material which is continuous except for shrinkage cracks. The mobility of the ground-mass is shown by flow structures (under crossed nicols small areas adjacent to one another and parallel streaks show marked changes in birefringence). In addition some 'lehm' fabrics have minor amounts of stable elements such as flecks and concretions of iron and manganese. In contrast 'erde' fabrics are completely stable and are made up of flocculated aggregates which show little or no alteration under crossed nicols. These fabrics have numerous empty cavities within their ground-mass and contain in addition secondary concretions of iron and manganese. Many soil horizons have composite 'erde'–'lehm' fabrics and this is the case with the B horizons of certain mull forest soils formed from loess and brickearth in southern England and parts of Europe. Here the stable braunerde fabrics contain in addition deep-yellow colloidal material which lines the cavities and cracks. These mobile features have been called *sol lessivé* (Dalrymple, 1955) and are thought to be similar to features described from the fabrics of para-braunerdes from Germany by Altemüller (1956) and Kubiena (1956) and of grey-brown podzolic soils from eastern United States by Frei & Cline in 1949.

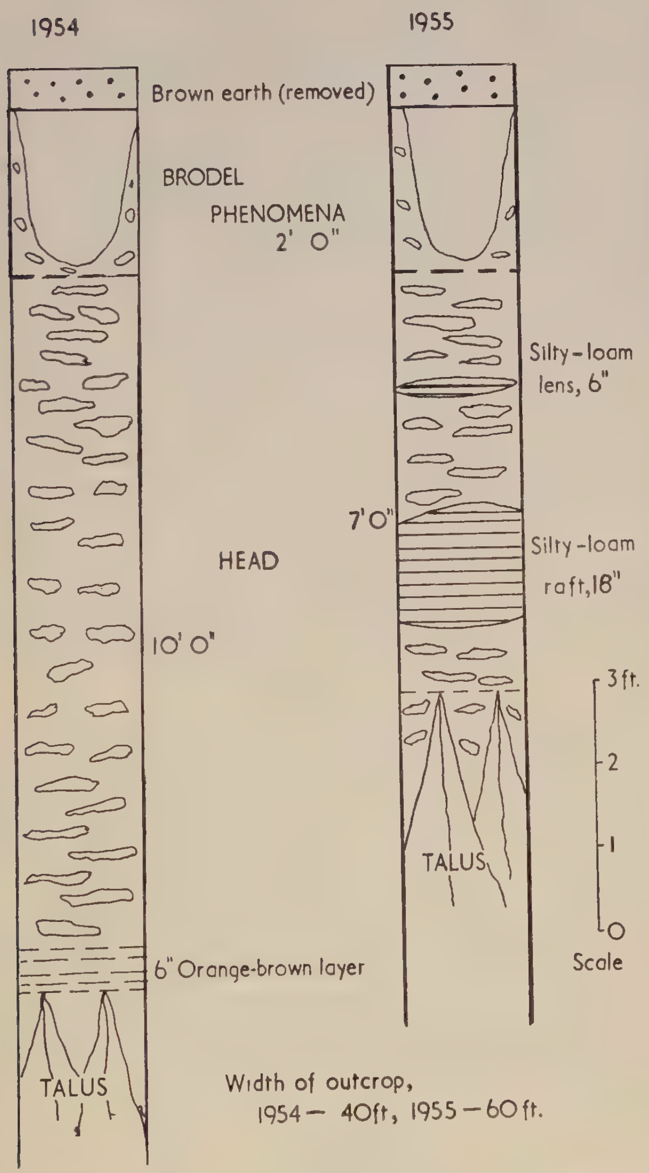

Fig. 1. Schematic diagram of the sections seen at Penfold's Pit, Slindon, in 1954 and 1955

In order to confirm that this thin orange-brown layer really formed a well-marked horizon, the site was revisited in 1955. This section given in Fig. 1 is probably some several score feet to the north of that previously seen, and again some seven feet of head with similar brodel pockets and a brown earth soil are visible. Below seven feet the section is obscured by talus and the orange-brown layer was not observed. Within the head, however, there are two silt-loam lenses brown in colour, which unlike the rest of the section are non-calcareous. The upper lens occurs one foot below the base of the brodel pockets and has a maximum thickness of six inches. It appears to be of only local occurrence since it dies out laterally within a few feet, but the lower lens, which is darker in colour and contains numerous manganese concretions, seems to form a raft of material about one foot six inches thick, though it does thin somewhat to the east.

In thin section the head material has rotlehm fabrics similar to those previously described, whilst the two silt-loam lenses contain small round concretions of iron in a ground-mass of mineral grains of fairly uniform grain size (0.06–0.006 mm.), which are held together by brown flocculated aggregates. In the case of the upper lens this stable braunerde fabric is permeated by thin conducting channels most of which contain deep-yellow colloidal material. These *sol lessivé* features, however, are much more prominent in the fabric of the lower lens and some of the mineral grains are coated with colloidal material, whilst all the cavities and conducting channels[1] are lined or filled with deep-yellow material showing marked flow-structures.

5. CONCLUSIONS

(a) Identification and Primary Origin of Fossil Soil Material

It was hoped to identify any fossil soil horizons occurring in the Pleistocene deposits at Penfold's Pit by macro- and, in particular, micromorphological techniques. Thus, the presence of rotlehm fabrics in the head material suggests that the primary weathering and pedogenic processes giving rise to its formation must have occurred under tropical or subtropical climatic conditions and so did not take place during the Pleistocene. Similar rotlehm fabrics have been observed from thin sections of Pliocene deposits, Clay with Flints and plateau brickearth material from many sites in Surrey and Kent (Dalrymple, 1955). Thus, the head at Penfold's Pit probably represents weathered Tertiary material which has been secondarily moved by solifluction during one or more cold phases of the Pleistocene.

The other fossil soil horizons observed within the head all have braunerde fabrics with *sol lessivé* features. The fabric of the orange-brown layer differs

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[1] Conducting channels within the ground-mass of a fabric may result from the presence of burrowing animals and plant roots or from shrinkage on drying.

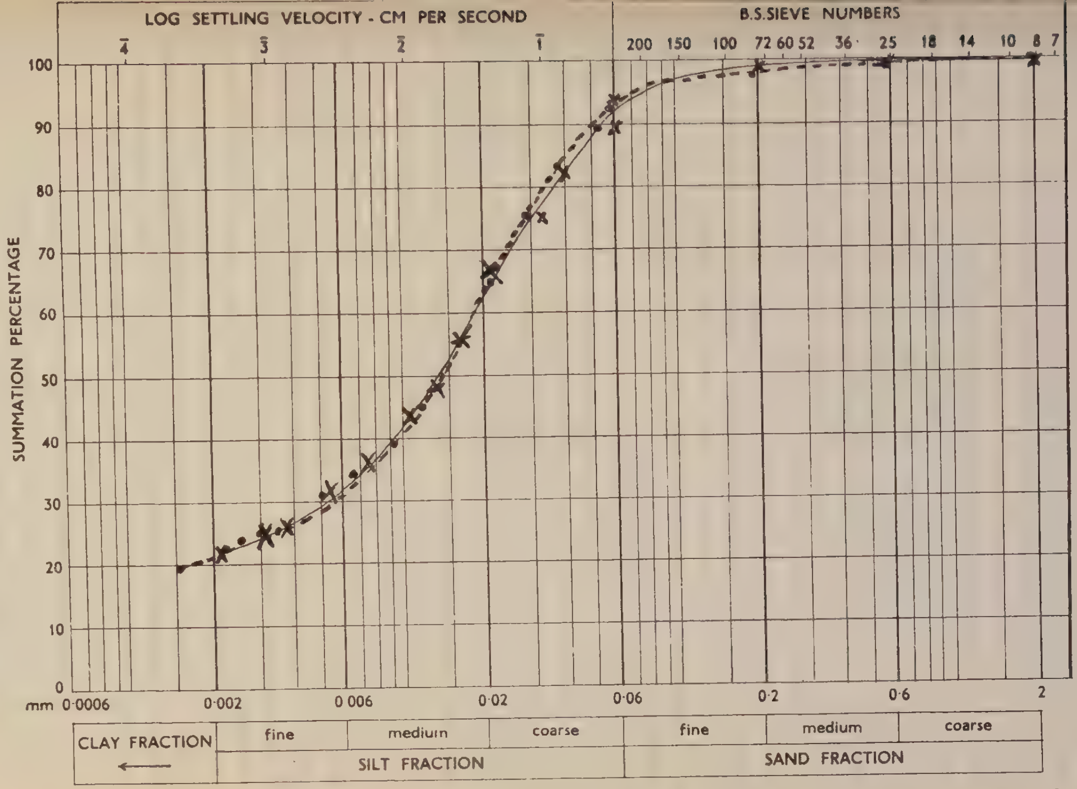

Fig. 2. Comparative sieve analysis of (a) —×—×— Lower silty lens in head, Penfold's Pit, Slindon, Sussex, and (b) —●—●— Intermediate brown soil, De, Achenheim, Alsace

from those of the two lenses of clayey-silt material in grain size and amount of colloidal material present. The actual soil types represented by these fabrics is not yet certain,[1] but they must result from soil-forming process acting under temperate climatic conditions. Thus, unlike the head, these deposits were probably originally derived from soils forming in the mild phases of the Pleistocene.

Similar fabrics have been observed (Dalrymple, 1955) from buried interstadial and interglacial soils from loess sections in southern England (for example, Ebbsfleet, Kent) and northern France (for example, Saint Pierre-les-Elbeuf, near Rouen). In fact, the fabric of the lower raft of silty material is almost identical with that of the B horizon of the fossil soil of the First Interstadial of the Last Glaciation from Saint Pierre-les-Elbeuf. This evidence suggests that the two lenses in the 1955 section might represent weathered loess incorporated within the solifluction deposit. This is quite likely, since this part of southern England, during the cold phases of the Pleistocene, appears to have been a transitional region between continental steppe conditions favouring loess formation and maritime conditions favouring solifluction.

In addition a mechanical analysis was carried out on the lower raft of silt-loam and the results compared with that of the 'Intermediate brown soil (De)' of the Last Interglacial from Achenheim in Alsace (Zeuner, 1953). The former contained 57% coarse and medium silt fraction (0.06–0.006 mm.); 12% fine silt (0.006–0.002 mm.) and 21% clay (less than 0.002 mm.) and these results agree remarkably well with those of the weathered loess from Achenheim, 60%, 11% and 21% respectively (Fig. 2). The similarity of these curves is due originally to wind sorting, but, since this might be an inherited character, all that can be deduced is that the deposit at Slindon represents weathered material mainly of the silt grade. However, the similarity of these results and of the fabrics of the lenses to those of Pleistocene soils from loess sites in Great Britain and Europe strongly suggests that the material at Slindon represents rafts of weathered loess subsequently incorporated within the head.

In contrast the fabric of the orange-brown layer shows that this material is not a weathered silt-loam of the type just described. It was formed under temperate climatic conditions, however, and it may well represent weathered soil material formed on and from the head.

(b) Relative and Absolute Chronology of Deposits

The marine sand in the centre of Penfold's Pit reaches a thickness of some fourteen feet and may represent an intertidal beach or an off-shore bar. The determination of its exact relationship to contemporary sea-levels is not certain, but the level of the rock-cut platform is at about ninety-eight to one hundred feet O.D. (Pyddoke, 1950) and this confirms that the whole group of beach deposits belongs to the Tyrrhenian. At Barnfield Pit, Swanscombe, Kent,[1] the surface of the 'upper loam' is at 110 feet and agrees closely in height with the surface of the sand at Penfold's Pit. This is only to be expected since both are adjusted to high-water mark, but in contrast the rock-cut platform is at seventy-five feet O.D. at Barnfield Pit and at ninety-eight to one hundred feet O.D. at Penfold's Pit. There is no need to postulate, however, that the beach at Penfold's Pit necessarily represents an earlier phase of the advance of the Tyrrhenian sea since, if the mean sea-level was at ninety feet O.D., there is no reason why a short distance from the beach the height of the rock-cut platform should not be some fifteen feet lower.

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[1] The relationship of braunerde, braunerde with *sol lessivé* and grey-brown podzolic fabrics to brown earths and grey-brown podzolic soils is not yet finally established.

The only human artifact known to have been found in Penfold's Pit is an unabraded hand-axe. It is of Middle Acheulian facies and was found lying upon the surface of the marine sand (Pyddoke, 1950). This hand-axe agrees with the implements found at Barnfield Pit, so, archaeologically as well as morphologically, the marine deposits in Penfold's Pit belong to the Tyrrhenian and confirm a date for the marine sands in the Great or Penultimate Interglacial.

In the centre of the pit the head rests directly on the beach deposits, thus the deposition of the head must post-date the formation of the Tyrrhenian beach. If its deposition is due to the slumping of the cliff face, as suggested by Zeuner (1952), this would occur at the latest soon after the maximum advance of the sea. There is, however, no evidence of the marine sands ever having been observed *in situ* in the northern face of the pit and the 1954 and 1955 sections probably lie well beyond the line of the fossil cliffs. If so, the head in these sections must have been deposited by solifluction during a cold phase, possibly that immediately subsequent to the formation of the Tyrrhenian beach. Thus, the head probably represents fossil soil material originally formed in a subtropical or tropical environment and deposited by solifluction during the Penultimate Glaciation on the Penultimate Interglacial land surface and the Tyrrhenian beach deposits.

Any soil material forming from the head on the old land surface contemporaneously with the formation of the fossil beach during the Penultimate Interglacial may have become incorporated within the head as a result of solifluction during the Penultimate Glaciation. This may account for the occurrence of the orange-brown horizon at the base of the 1954 section, since the micromorphological evidence suggests that it represents head material weathered under humid-temperate conditions. On the other hand the silt-loam lenses appear to represent fossil soil material weathered during a mild phase from loess. This material would have been deposited in the neighbourhood during the preceding cold phase and the weathered material subsequently incorporated in the head as a result of solifluction during the succeeding cold phase.

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[1] This pit is the site from which the water-laid deposits of the '100 foot terrace' of the Thames were first described (Burchell, 1933 and 1935; and Zeuner, 1945 and 1952).

It is possible that the mild and cold phases represented by these fossil soil horizons in the head related to the Last Interglacial and the Last Glaciation, but from the field and laboratory evidence there seems no justification for correlating the two silt-loam lenses with weathered Older and Younger Loess respectively. Therefore it is considered that the deposition of the loess, its weathering and subsequent incorporation in the head probably all occurred during cold and mild interstadial phases of the Penultimate Glaciation. The only evidence for a cold phase since then are the brodel pockets at the surface of the head, and these probably relate to the Last Glaciation. Finally on top of the head are the brown earth soils which represent the moist-temperate conditions of the Postglacial.

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REFERENCES

ALTEMÜLLER, H. J. 1956. Mikroskopische Untersuchung einiger Löss-Bodentypen mit Hilfe von Dunnschliffen. *Z. PflErnähr. Düng.*, **72,** 152–67.

BURCHELL, J. P. T. 1933. The Northfleet Fifty-foot submergence later than the Coombe Rock of Post-Early Mousterian Times. *Archaeologia*, **83,** 67–92.

———. 1935–6. The Ebbsfleet Channel series. *Geol. Mag.*, **72,** 90–1; 327–31 and **73,** 91–2; 550–4.

CALKIN, J. B. 1934. Implements from the Higher Raised Beaches of Sussex. *Proc. prehist. Soc.*, **7,** 333–47.

DALRYMPLE, J. B. 1955. Study of Ferruginous Horizons in Archaeological Sections. *Thesis*, London University, Institute of Archaeology.

FOWLER, J. 1932. The 'One Hundred Foot' Raised Beach between Arundel and Chichester, Sussex. *Quart. J. geol. Soc. Lond.*, **88,** 84–99.

FREI, E. & CLINE, M. G. 1949. Profile Studies of Normal Soils of New York. II. Micromorphological Studies of the Grey-brown Podzolic-brown Podzolic sequence. *Soil Sci.*, **68,** 333–45.

KUBIENA, W. L. 1948. *Entwicklungslehre des Bodens*. Wien.

———. 1953. *The Soils of Europe*. London.

———. 1956. Zur Mikromorphologie, Systematik und Entwicklung der rezenten und fossilen Lössböden. *Eiszeitalter und Gegenwart*, Öhringen, **7,** 102–12.

OAKLEY, K. P. & CURWEN, E. C. 1937. The Relation of the Coombe Rock to the 135-foot Raised Beach at Slindon, Sussex. *Proc. Geol. Ass., Lond.*, **48,** 317–23.

PALMER, L. S. & COOKE, J. H. 1923. The Pleistocene Deposits of the Portsmouth District and their Relation to Man. *Proc. Geol. Ass., Lond.*, **34,** 253–82.

PRESTWICH, J. 1892. The Raised Beaches and 'Head' or Rubble Drift of the South of England. *Quart. J. geol. Soc. Lond.*, **48,** 253–343.

PYDDOKE, E. 1950. An Acheulian Implement from Slindon. *Ann. Rep. Univ. Lond. Inst. Arch.*, **6,** 30–3.

REID, C. 1887. On the Origin of the Dry Chalk Valleys and of the Coombe Rock. *Quart. J. geol. Soc. Lond.*, **43,** 364–73.

————. 1892. The Pleistocene Deposits of the Sussex Coast and their Equivalent in Other Districts. *Quart. J. geol. Soc. Lond.*, **48,** 344–61.

————. 1903. The Geology of the Country near Brighton and Worthing. *Mem. geol. Surv. U.K.*

ZEUNER, F. E. 1945. The Pleistocene Period. Its Climate, Chronology and Faunal Succession. *Ray Soc. Publ.*

————. 1952. *Dating the Past*. London.

————. 1953. Loess Balls from the Lower Mousterian of Achenheim (Alsace). *J. R. anthrop. Inst.*, **83,** 65–70.

A Late Pleistocene Rodent and Amphibian Fauna from Levaton, near Newton Abbot, South Devon

by J. N. CARRECK

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ABSTRACT: A collection of remains of rodents and amphibians from an undescribed Pleistocene fissure filling in the Devonian limestone at Levaton, near Newton Abbot, is described. Eight species are recognised and their distribution at other localities is given. The faunal assemblage, and the deposit from which it was obtained, are assigned to the first half of the Last Glaciation. The remains are seen to be of animals that died at some distance from the fissure.

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1. INTRODUCTION

A NUMBER of bones and teeth of rodents, and bones of amphibians, has been obtained from the filling of a fissure in the Middle Devonian limestone at Levaton, about three and a half miles WSW. of Newton Abbot, South Devon, by Mr. W. A. Cheesman, of Buckfastleigh, near Totnes. He has also collected remains of the larger Pleistocene mammals from this fissure, which he discovered in 1950. The rodent and amphibian material was obtained from near the base of the fissure in a deposit which Mr. Cheesman has termed the Lower Comminuted Shale Bed, an accumulation of fine water-laid debris from Devonian shales outcropping in the district. These small fossils include the remains of voles, a field mouse, frog and probably toad, as described below. Most of the material is in a fragmentary condition, and many of the mandibular rami of rodents in the deposit lack their posterior extremities.

The entire collection is at present in the possession of the finder.

2. THE FAUNA

The following genera and species are represented. Each dated reference to species, within parentheses, refers to the first published record.

(a) Order: *RODENTIA*
Subfamily: MICROTINAE

Microtus cf. *ratticeps* (Keyserling & Blasius).

Two right mandibular rami, and an isolated left m_1.

These vole remains are almost certainly referable to *M. ratticeps*, which is known from the cave earth of Kent's Cavern, Torquay (Hinton, *in* Kennard, 1945), the later Taplow Terrace deposits of the Thames at Crayford, Kent (Newton, *in* Whitaker, 1889), and the Ightham Fissures in Kent (Newton, 1894). It still lives in Northern Europe and Asia, and southwards into Holland, North Germany and Northern Hungary.

M. anglicus Hinton.

The interorbital region of a skull, two right and two left mandibular rami, and a left m_1.

One of the right rami is of an arvaloid form of the species. The above material is undoubtedly of the extinct *M. anglicus*, known from the cave earth of Kent's Cavern (Hinton, *in* Kennard, 1945), from the Ightham Fissures (Newton, 1894), and from the Ponder's End stage of the Thames succession (Hinton, 1926).

M. cf. *anglicus* Hinton.

A fragment of the interorbital region of a skull, two right and two left mandibular rami, and a right m_1.

These remains are most probably referable to this species, but are insufficient for precise determination.

M. cf. *arvalis* (Pallas).

Two left mandibular rami.

This material closely approaches *M. arvalis*, to which it should be referred in all probability. The species still lives on the Continent, from the Baltic to the Pyrenees and Northern Italy. It is known in the fossil state from the Ightham Fissures (Newton, 1894).

Microtus sp., *arvalis* group, cf. *corneri* Hinton.

Three left mandibular rami.

These specimens are referable to a member of the *M. arvalis* group, very probably the extinct *M. corneri*, although one is not very typical. Similar material is known from the cave earth of Kent's Cavern (Hinton, *in* Kennard, 1945).

Microtus sp., *arvalis* group.

Two left mandibular rami, a right mandibular ramus, and a slightly worn right m_1 of a very young individual.

These examples are assigned to the *M. arvalis* group, represented in the cave earth of Kent's Cavern, but they are not further determinable.

Microtus sp., cf. *arvalis* group, or cf. *nivalis* (Martins) group.

A left mandibular ramus.

It is impossible to state to which species or group this specimen should be assigned. The *M. nivalis* group occurs in the late Taplow Terrace deposits of the Thames at Crayford (Hinton, 1907), in deposits of similar age such as in the Clevedon Cave, Somerset (Hinton, 1907), and is represented in the living state on the Continent at present.

Microtus sp.

A left mandibular ramus, two examples of m^1, two of m^2, two of m^3, and a right m_3.

None of these remains is sufficiently diagnostic for trivial determination.

Arvicola abbotti Hinton.

A left, and a right, mandibular ramus.

These are referable with reasonable certainty to this extinct vole, which is highly specialised for burrowing, and is known from the cave earths of Kent's Cavern (Hinton, *in* Kennard, 1945), the Happaway Cave at Torquay, probably the Brixham Cave in Torbay, and of Torbryan Cave near Newton Abbot (Hinton, 1926).

Arvicola sp. (? *abbotti* Hinton).

A left mandibular ramus, and a right femur.

There is nothing to suggest that these remains are of the existing *A. amphibius* (Linné), and they are probably of *A. abbotti*, but no trivial name can be confidently assigned to them.

Subfamily: MURINAE

Apodemus cf. *sylvaticus* (Linné).

A right mandibular ramus lacking its posterior portion, with only the m_1 and the incisor preserved. Somewhat suggestive also of *A. lewisi* (E. T. Newton).

The single cheek tooth remaining in this ramus shows a small but definite anterior accessory cusp, which is usually well developed in the Long-tailed Field Mouse, *A. sylvaticus*, but is absent or very small in *A. lewisi*, which, although tentatively regarded as an extinct species, may be identical with the existing *A. flavicollis* (Melchior). This mode of distinction between the first two species is not entirely reliable, but the morphological characters of the present tooth, and the size of the ramus, appear to associate it with the former species rather than with the latter. *A. sylvaticus* is known only from the Late Pleistocene, occurring in the Ightham Fissures with *A. lewisi* (Newton, 1894), and in British and Irish cave deposits, and from the Holocene.

Bones and Incisors of Small Rodents. Nine upper incisors, one upper incisor in a fragment of a premaxilla, two lower incisors, one lower incisor in part of a mandibular ramus, four ulnae, seven humeri, a broken scapula, eleven conjoined tibiae and fibulae, a portion of a fused tibia and fibula, eight femora and seven portions of others, two pelvic fragments, three metapodials and eight vertebrae.

These may be separated by their relative sizes and proportions into about three groups. Most or all are referable to *Microtus* spp., but some may be of *Apodemus*.

(b) Class: *AMPHIBIA*
Order: *SALIENTIA*

Rana sp.

Four radio-ulnae, three humeri and nine distal portions of others (two of male individuals), five tibio-fibulae and a shaft of a tibio-fibula, two fragments of ilia, four larger fragments of the pelvic girdle, three calcanea, one conjoined astragalus and calcaneum, and four vertebrae.

This material agrees satisfactorily with Recent frog remains, but it is preferable not to attempt trivial determination. Remains of *Rana temporaria* Linné were abundant in the Ightham Fissures (Newton, 1894).

Cf. *Bufo* sp.

Two femora and the shafts of two others, three tibio-fibulae and the shaft of another.

These appear to differ from those of *Rana*, and to closely resemble a series of Recent *Bufo* material with which they have been compared, but the fossil bones are imperfect and until more diagnostic remains such as ilia can be recovered from the fissure the presence of toad must remain uncertain. Six ilia of *Bufo bufo* Linné are known from the Ightham Fissures (Newton, 1894).

CONCLUSIONS

The vole assemblage listed above, of apparently five species, is indicative of a Late Pleistocene date for that part of the fissure filling from which it was obtained, and there is nothing to suggest that the deposit is of more than one age. The presence of *Microtus* cf. *ratticeps*, *M. anglicus*, *M.* cf. *arvalis*, *M.* cf. *corneri*, and *Arvicola abbotti*, indicates a date approximately equivalent to the Ightham Fissure stage of Kent (Abbott, 1894; Newton, 1894; Hinton, 1926), of which this small fauna is highly characteristic, and such an assemblage is also known from the Late Pleistocene cave earth of Kent's Cavern (Hinton, *in* Kennard, 1945). Since the Late Glacial Ightham Fissure stage is intermediate in age (Hinton, 1926) between the Lower Crayford Brickearths (Kennard, 1944) and the Lea Valley Arctic Bed or

Ponder's End stage (Warren, 1912), the Levaton rodent and amphibian fauna may be assigned to the first half of the Last Glaciation.

The fragmentary condition of the remains of small vertebrates from the Levaton Fissure indicates that the animals did not fall into the fissure during life, but that their skeletal remains were washed into it after they had died and their bodies had decomposed.

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REFERENCES

Abbott, W. J. L. 1894. The Ossiferous Fissures in the Valley of the Shode, near Ightham, Kent. *Quart. J. geol. Soc. Lond.*, **50**, 171–87, 210 and 211 (the first published account of the Ightham Fissures).

Hinton, M. A. C. 1907. On the Existence of the Alpine Vole (*Microtus nivalis*, Martins) in Britain during Pleistocene Times. *Proc. Geol. Ass., Lond.*, **20**, 39–58 (gives records from various localities, and theoretical discussion).

———. 1915. Note on British Fossil Species of Apodemus. *Ann. Mag. nat. Hist.* (8), **15**, 580–84 (describes *A. sylvaticus* and *A. lewisi*; records the latter from the cave earth of Kent's Cavern and the Happaway Cave).

———. 1926. *Monograph of the Voles and Lemmings* (*Microtinae*), *Living and Extinct. Vol. I.* British Museum (Nat. Hist.), London (lists the Microtine fauna of the Ightham Fissures, and describes *Arvicola abbotti* from Ightham, Happaway Cave, probably the Brixham Cave, and from Torbryan Cave. Gives chronological position of the Ightham Fissure deposits on pp. 125–36).

Kennard, A. S. 1944. The Crayford Brickearths. *Proc. Geol. Ass., Lond.*, **60**, 121–69 (a masterly summary, with revised interpretation).

———. 1945. The Early Digs in Kent's Hole, Torquay. . . . *Ibid*, **56**, 156–213 (gives notes on the Microtinae of Kent's Cavern by M. A. C. Hinton, on pp. 184–5).

Newton, E. T. 1894. The Vertebrate Fauna collected by Mr. Lewis Abbott from the Fissure near Ightham, Kent. *Quart. J. geol. Soc. Lond.*, **50**, 188–211 (describes and figures *Apodemus sylvaticus* and *A. lewisi*, with the Microtine fauna).

Warren, S. H. 1912. On a Late Glacial Stage in the Valley of the River Lea, subsequent to the Epoch of River-Drift Man. *Ibid.*, **68**, 213–51 (the discoverer's first account, with palaeontological appendices by various authors).

Whitaker, W. 1889. The Geology of London and of part of the Thames Valley. *Mem. geol. Surv. U.K.* (first record of *Microtus ratticeps* from Crayford, by E. T. Newton on p. 336).

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